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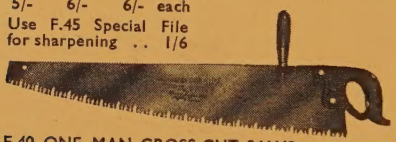

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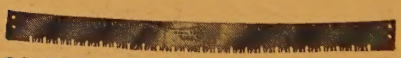

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THE IMPORTANCE OF FORESTRY is being realized more and more in Great Britain. The number of foresters is increasing steadily, and a forestry profession is gradually being built up. It is intended that this Society should be representative of the profession. Those who are not engaged in the practice of forestry or the allied sciences are cordially invited to join the Society as Ordinary Members.

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SOCIETY'S MEDAL. The Council has resolved that the Society award a Medal from time to time to any individuals who may have rendered eminent services.

FORESTRY

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THETFORD CHASE, WITH NOTES ON SWAFFHAM FOREST AND THE KING'S FOREST

BY JAMES MACDONALD

(Divisional Officer, Forestry Commission)

INTRODUCTION.

THE new State forest of Thetford is situated near the town of that name in the south-west of Norfolk and extends over about 44,000 acres in that county and in the neighbouring county of Suffolk.

The forest of Swaffham lies to the north of the Thetford block. Extending to 5,952 acres, it is composed of a number of areas to the south and west of the town of Swaffham and another detached section near Mundford on the northern boundary of Thetford.

The King's Forest lies to the north of Bury St. Edmunds. Formerly part of the Culford Estate, it was acquired in 1935 and extends to 5,990 acres. It owes its name to its selection as one of the forests chosen to commemorate the Silver Jubilee of His Majesty King George the Fifth.

The district in which these forest areas have been formed is known as the Breckland, a region possessing certain unique characteristics, good descriptions of which may be found in publications by Clarke (3) and Schober (9); both these works contain very full bibliographies.

The Forestry Commissioners commenced planting at Thetford in the winter of 1921–2 on land leased from the first Earl of Iveagh, south of Brandon, and at Swaffham, in the same year, on part of the Cockley Cley estate. The first acquisitions of land were followed speedily by others, and developments of this kind have continued up to the present time. Table I gives details of the various acquisitions of land at Thetford. The numbers refer to the map in Text-fig. 1.

Of the land acquired at Thetford, 76 per cent. has been obtained by purchase and 24 per cent. by lease; at Swaffham the percentages are 33 and 67 respectively.

LOCALITY DESCRIPTION.

Topography. The Breckland district is an area of gently undulating ground which rises out of the Fen on the western side and to the north, east, and south merges gradually into the surrounding country. Elevations are not high. Round Brandon and Methwold the land is less than 50 feet above sea-level while, among the highest points, Cockley Cley Heath is only 171 feet, High Ash, 181 feet, High Lodge 150 feet, Shakers Lodge 178 feet, and Rubbing-house Covert (King's) 183 feet. The Thetford Forest area is traversed by the Little Ouse River between Thetford and Brandon, and in this valley elevations

are less than 20 feet above sea-level. Along the northern boundary of Thetford Forest, the River Wissey runs in a parallel direction, and to the south of the King's Forest the River Lark, another tributary of the Great Ouse, also pursues a westerly course. Apart from these rivers, the numerous small valleys and

TABLE I. *Thetford. Acquisition of land*

No.	*Estate.*	*Area, acres.*	*Date of acquisition.*
1	Downham Hall	4,944	1923
2	Croxton	4,197	1927
3	Elveden	3,159	1923
4	Lynford	7,143	1924
5	Methwold	1,562	1926
6	Heath Farm	227	1928
7	Thetford Warren	2,908	1924
8	Weeting	3,830	1926
9	Brandon Park	1,745	1930
10	West Harling	3,077	1930
11	Hockham	2,025	1930
12	Roudham	1,485	1932
13	Hockwold	1,448	1932
14	Feltwell	179	1933
15	Mildenhall	1,565	1934
16	Stow Heath	335	1926
22	Brandon Park	839	1936
23	Wretham	3,463	1939
	Total	44,131	..

Similar details for Swaffham are given in Table II.

TABLE II. *Swaffham. Acquisition of Land*

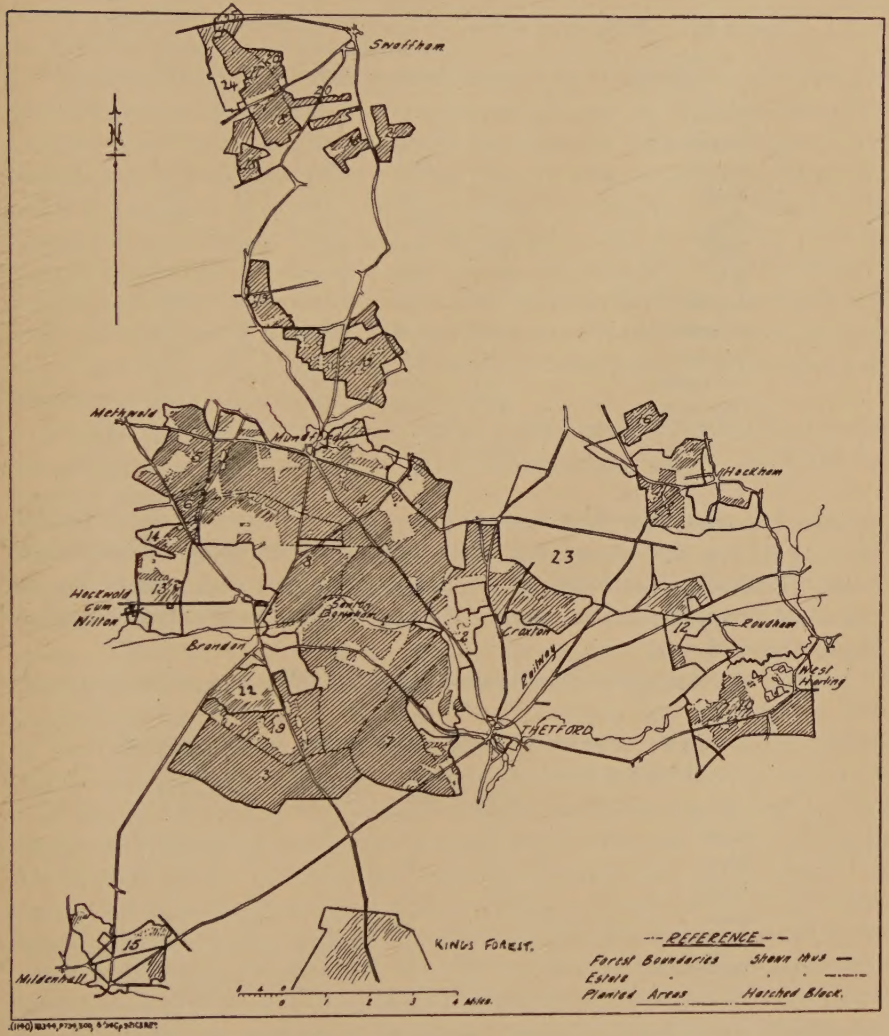
No.	*Estate.*	*Area, acres.*	*Date of acquisition.*
17	Beechamwell	822	1924
18	Cockley Cley	1,306	1922
19	Didlington	2,142	1925–1927
20	Snailspit	377	1924
21	Pickenham	195	1922
24	Beechamwell	918	1936
25	Swaffham Heath	192	1935
	Total	5,952	..

depressions, which occur all over the area, are dry, with the exception of the well-known meres on the Wretham and Croxton sections of Thetford.

Climate. A valuable discussion of the climate of Breckland may be found in Watt's paper 'Studies in the Ecology of Brockland' (12). This makes it clear that the climate of this district is more extreme in its character than that of the rest of the British Isles and approaches, to some extent, the continental type.

The average rainfall is in the neighbourhood of 23–4 inches per annum, and the monthly rainfall for the last six years at Lynford, in the northern half of Thetford Forest, is set out in Table III.

This table shows that there are considerable variations from year to year, and



there is a striking contrast between the rainfall in a dry year like 1934 and wet years like 1936 and 1937. Periods of drought in the spring and summer are not uncommon and the worst of these in recent years was in 1938, when only 1·70 inches of rain fell during the three months February–April. A period of drought at that season of the year has unfortunate and sometimes disastrous results on newly planted stocks in the forest and on seed-beds and transplant lines in the nursery. The fire danger is also greatly accentuated.

The range of temperature in the Breckland district is slightly more extreme than in most parts of Great Britain. Summer temperatures tend to be high and winter temperatures low, but the most important feature is the regular occurrence of frosts in the late spring and early summer. This is of the

TABLE III. *Monthly Rainfall at Thetford (Lynford), in Inches*

Month.	*1934.*	*1935.*	*1936.*	*1937.*	*1938.*
January . . .	1·31	1·93	2·58	3·31	2·31
February . .	0·46	1·94	2·42	2·95	0·63
March . . .	1·71	0·55	0·64	3·76	0·53
April . . .	1·83	2·29	1·54	2·75	0·54
May . . .	1·04	0·82	1·42	2·03	2·17
June . . .	2·33	3·15	2·78	1·47	1·19
July . . .	1·18	0·73	5·14	1·70	1·28
August . . .	1·66	0·94	1·13	1·89	1·93
September . .	1·92	3·93	3·60	1·95	2·83
October . . .	1·50	2·26	1·54	1·66	2·86
November . .	1·13	3·10	2·69	1·79	2·14
December . .	4·13	1·97	1·38	3·04	2·87
	20·20	23·61	26·86	28·30	21·28

greatest importance for the forester, because all frost tender species, if planted without shelter, are subject year after year to the crippling effect of these frosts. Table IV gives details of the number of nights with ground frost at Thetford during the last five years. The figures relate to the months April to September inclusive.

Most of the damage is done by frosts in May when the young shoots are

TABLE IV. *Number of nights with ground frost. Thetford*

	1934.	*1935.*	*1936.*	*1937.*	*1938.*
April . . .	8	10	18	5	23
May . . .	6	8	5	3	11
June . . .	..	1	1	..	1
July . . .	..	1	..	..	..
August . . .	1	4	..	..	2
September . .	1	3	1	3	3

unfolding and tender, and they are always more severe in the valleys and hollows.

Geology and Soils. The underlying rock is the chalk, which comes close to the surface in various parts of Thetford and Swaffham forests, but, almost everywhere, it is overlain by deposits of glacial origin, the most important of these being the Chalky Boulder Clay, which occurs over most of the area. Others can, however, be recognized, and the position is further complicated by the presence over a considerable part of the district of a covering of blown sand

of more recent origin. The soils are sandy and they vary from a very thin sand over chalk to deep podsolized sands. Watt (13) has identified a series of soil-types in the Breckland beginning with highly calcareous soils with a thin covering of sand over the chalky Boulder Clay and passing through less calcareous soils to a brown forest soil type, and finally to a well-marked podsol. The podsol types are not common within the forest boundaries, but they occur on the low-lying land at Brandon Park.

Vegetation. There are several well-marked types of vegetation, of which the most widespread is the 'grass-heath' composed principally of *Festuca ovina* and *Agrostis* spp. On unenclosed land this is frequently very heavily grazed by rabbits and it may take three or four years to recover its vigour after the rabbits have been removed. *Carex arenaria* is abundant over considerable tracts, but according to Watt it is really dominant only on relatively recently drifted sand. *Calluna vulgaris* is less common, although it is found in different localities all over the forest, but bracken—*Pteridium aquilinum*—is widespread over extensive areas. Locally, and principally on areas of blown sand, patches occur on which there is little vegetation save lichens, principally *Cladonia* spp. Ground of this type is not extensive in area.

On land which has been recently cultivated but has become derelict, there is generally a rich crop of herbaceous species among which may be mentioned the ragwort (*Senecio jacoboea*).

PREVIOUS UTILIZATION OF THE LAND.

Immediately prior to acquisition by the Forestry Commissioners most of the land at Thetford and the adjoining forests was either derelict arable or open heath. There were included, however, in the acquisition certain areas of cultivated land, and these have mostly been retained as farms or allotted to nurseries or Forest Workers Holdings. It is estimated that about 19 per cent. of the land planted in the Breckland district had, within fairly recent times, been under the plough, but much of this had been cultivated in recent times only for food for game, while some had only been broken up during the War under the emergency food-production schemes of that time. R. R. Clarke, in his account of the historical and economic development of Breckland (2), points out that the appearance of this district, as it was before afforestation, was largely the result of changes introduced by the enclosures at the end of the eighteenth century. Before that time the area was open, and there are signs in some places of a form of management similar to the Scottish infield-outfield system. With the enclosures, however, came the planting of hedges and shelter-belts of conifers, mostly Scots pine, and a more intensive agriculture in which sheep played an important part. But the agricultural depressions of the second half of the nineteenth century, combined, possibly, with a reduction in soil fertility, hit the Breckland heavily, and gradually the land began to fall out of cultivation. At the same time the sporting steadily increased in value, and by 1914 this had become the principal interest of the district. The concentration on sporting led to further planting of trees in belts and small coverts.

ACQUIRED PLANTATIONS.

Previous to the enclosures there was apparently little woodland in the district, apart possibly from patches on the fen land in the river valleys, and publications by Darby (4) and Beevor (1) have shown that in the eleventh century the only considerable areas of woodland then existing were to be found on the borders of the district, and that, apart from one area at Langford in the Wissey valley, the area now occupied by Thetford Chase was devoid of woodland.

The hedges of Scots pine and, less frequently, of Norway spruce which were first planted to prevent the blowing of the soil from the cultivated fields, are now no longer planted, nor are they maintained except on one or two estates where regular clipping is still carried out. But the remains of these overgrown pine and spruce hedges with their bizarre shapes are still a prominent feature by the roadsides in the Thetford district.

Shelter belts of Scots pine and other conifers and of oak, 80 to 100 years old, are still numerous, especially at Swaffham and the King's Forests. These are often only one chain or two chains in width, and in the more exposed or difficult sites the growth is poor; they have all suffered from neglect, and the pine belts have been damaged in the past by bark-beetles which have been allowed to breed in wind-blown and dying trees. It has been estimated that the old belts still standing at Swaffham contain about 140,000 cubic feet, of which 123,000 cubic feet is of Scots pine. At the King's Forest the estimated content of the belts is 145,000 cubic feet, of which 106,000 cubic feet is Scots pine and 26,000 cubic feet oak. The younger belts, planted for shelter and to serve the sporting interest during the present century, are generally composed of a mixture of species among which Corsican and Scots pine, Douglas fir, Norway spruce, and European larch are most frequently used.

Much of the woodland planted since the beginning of the nineteenth century was felled during the War and the immediate post-War periods, but felling has continued in the district since those times. There still remain in Thetford, Swaffham, and the King's Forests about 2,000 acres of plantations, exclusive of belts, acquired with the various properties and now under management. These include areas of old and middle-aged oak of moderately good quality, some old conifers, and a useful series of young and middle-aged coniferous plantations, in which European larch and Scots pine are the most important species.

Mention ought also to be made of the natural regeneration of Scots pine in Brandon Park, which came up abundantly 25–30 years ago on a strongly podsolized soil. Most of the parent trees have now disappeared, but several of good type still remain, and where the rabbits have been excluded are beginning again to seed up the open spaces.

RATES OF GROWTH.

Measurements were made in 1918 of numerous sample plots and groups in the Thetford district, and these showed that Quality Classes II and III (British

Yield Tables) were those generally represented. There were, however, several plots of Quality Class I of which the following at Mildenhall are representative.

These plots were both growing on deep podsolized sands over the chalk. On the other hand, certain measurements taken in Brandon Park showed a very much poorer rate of growth, also on a podsolized sand, and in this instance trees almost 90 years old were only 40 feet in height, although they had grown quite well up to 30 years of age. This is quoted merely to indicate that here

TABLE V. *Scots pine. Mildenhall. Per acre*

Plot No.	*Age.*	*Height, ft.*	*Quarter-girth, inches.*	*No. of stems.*	*Basal area, sq. ft.*	*Volume under bark, cub. ft. Q.G.*
214	78	73	11½	180	166	4,450
216	79	75	11	170	142	4,025

and there throughout the new plantations areas of poor growth may be found in the future, although it is unlikely that the rate of growth of Scots pine will fall much below that of Quality Class II under reasonable management.

With regard to Corsican pine, two new permanent sample plots have recently been established at Thetford in acquired plantations between 30 and 40 years of age. It will be noted that these are both of Quality Class I, and this is likely to be the usual rate of growth on all but the very thin soils and those which are deep but strongly podsolized. Details are given in Table VI.

TABLE VI. *Corsican Pine. Thetford. Per acre*

		Main Crop					*Thinnings*			*Total*	
Plot No.	*Age.*	*Height, ft.*	*Quarter-girth, in.*	*No. of stems.*	*Basal area, sq. ft.*	*Volume, U.B. cub. ft.*	*No. of stems.*	*Basal area, sq. ft.*	*Volume, U.B. cub. ft.*	*Basal area, sq. ft.*	*Volume, U.B. cu. ft. Q.G.*
128	36	54	7⅛	397	140·1	3,040	189	36·8	718	176·9	3,578
129	38	59	8⅛	247	111·7	2,850	40	11·6	270	123·3	3,120

There are no sample plot measurements of other conifers, but from analyses of felled trees it would seem that the most likely Quality Class for Douglas fir is III and for European larch II–III.

THE NEW PLANTATIONS.

A good account of the methods employed in afforestation at Thetford in the earlier years of the Commissioners' activities has been given by Taylor (10) in the *Quarterly Journal of Forestry* for 1925. What follows in this paper refers mainly to methods in use at the present time, but these, where they differ from those originally employed, differ usually in details, and do not represent any revolutionary change in the technique of afforestation.

At the outset, as at the present time, the choice of species for planting on the open heath land was dictated not so much by the soil as by the climate, because what is required is a species which will withstand the unseasonable frosts, tolerate the conditions of drought which are periodically severe, and survive the high temperatures of the summer. The species which best fulfils these requirements is the Scots pine, which had already been successfully established in the district, and it was natural, therefore, that most of the early planting was done with this species. Growth was satisfactory, but as the pine developed the attacks of the Pine Shoot Moth increased and more attention in consequence began to be paid to Corsican pine, almost equally suitable, which was known to be less seriously affected by this insect. At present, more Corsican pine is being used in new planting than Scots pine, and this is likely to continue in the future. A certain amount of Douglas fir was also planted, with curiously varied results. Little planting of broadleaved species, other than beech, has been attempted until recent years, but in 1926 and 1927 large areas of beech were planted in different parts of Thetford Forest in mixture with European larch and Corsican pine which were included to serve as nurses. The beech in these plantations have had a chequered history. In a few places they have grown very well and are as good as the Corsican pine, but in many areas they have failed completely, while they have been damaged by frost, hares, deer, and, locally, by rabbits. The effect of excluding deer and hares is now being studied in a large enclosure made for the purpose, and there is no doubt that since its erection there has been a marked improvement in the beech. It is unfortunate that this should prove such a difficult species to establish at Thetford because it will be necessary in future to break up the large blocks of conifers, in the interest of safety from fire, by blocks of broad-leaved species, of which beech is one of the most suitable.

On old arable land, plantations of oak, with Scots pine as a nurse, are making fair progress, and this tree should be less difficult than beech to establish.

On old woodland sites it was at first the practice to replant with a conifer, either Scots pine or Douglas fir being used. At the present time, if the former woodland was coniferous, it is generally replaced by a conifer such as Corsican or Scots pine, but where the original crop was broadleaved it is replanted either with oak or with beech. This has been found to be more satisfactory, because conifers planted on the site of former broadleaved areas were apt to be smothered by the excessive growth of shrubs such as privet and snowberry, which were almost invariably planted in these woods in former times in the interests of the game.

The belts of broadleaved trees, planted along the roadsides for the sake of amenity, have for some time been a cause of concern to the local staff. Many of these are growing well, but there are still large stretches on which the growth is mediocre. The species principally employed was oak, with Scots pine as a nurse, but beech, sycamore, and other trees have also been used, and one interesting point which has emerged is the success which has attended the planting in these belts of the wild cherry (*Prunus avium*). This species has

proved frost-hardy and has grown strongly, and being ornamental it may prove a very useful tree for this purpose.

On the heath and old arable land the preparation of ground for planting is very simple and consists of ploughing a shallow furrow into which the plants are inserted. Planting in the bottom of the furrow gives the young plants a measure of protection from the sun in the summer, and for the first season at least a moderate amount of freedom from competing weed-growth. Two furrows are ploughed at a time by a special plough drawn by a Fordson tractor, and the operation is speedy and cheap. On ground covered by heavy growths of *Carex arenaria* ploughing is difficult, even if the sedge is burnt off beforehand, and the preparation of the ground is done by screefing a bare patch into which the plant is subsequently inserted. The same procedure is followed on old woodland sites where the stumps make ploughing impossible. On old, broad-leaved, woodland sites where there is small coppice and shrub growth the present practice is to clear the vegetation in groups of irregular size before planting. Where the coppice or other growth is tall it is first thinned out and then underplanted, usually with beech.

At the King's Forest, where Queen Mary's Avenue of beech, four miles long, is being planted, subsoiling before planting has been tried in order to promote aeration of the soil. The success of this policy is not yet established. In this avenue birch is being used as a nurse for the beech, and it is already making good growth and promising to serve its purpose admirably.

Planting is done with the common garden spade, which is inserted vertically into the ground and then levered backwards and forwards to stir up the soil. The plant is inserted with its roots hanging vertically, and great importance is placed on this point, because in some of the older plantations, patches of poor growth have apparently been due to bad planting in which the roots were bent almost at right angles when they were put into the ground.

For planting, 1+1 and 2+1 transplants of pine are usually employed, the former on land which carries little vegetation. The 1+2 transplant has been used to a certain extent for beating up, for which it is suitable in size, but it is an unsatisfactory plant and liable to die off in large numbers in seasons of drought. Various ages of Douglas fir and beech transplants have been used with irregular results, but it is almost certain that a large plant is much to be preferred in both species. One year seedlings of oak are regularly used with good results.

A certain amount of direct sowing with Maritime pine was carried out in 1923 at Thetford with moderate results, but little more was done with this form of establishment until 2 years ago, when 20 acres were sown with Corsican pine at the King's Forest. This succeeded much better than was anticipated. Direct sowings of oak and beech are not to be recommended on account of the large numbers of pheasants in the neighbourhood.

Reference has already been made to the natural regeneration of Scots pine at Brandon Park, and there is no doubt that this species will regenerate itself freely over most of the district, except possibly where the vegetation consists of

bracken. Seedlings of Corsican pine come up occasionally in considerable numbers near existing plantations, and larch and Norway spruce both appear from time to time as self-sown seedlings. In the pine plantations on the better soils, large numbers of oak seedlings have appeared, no doubt from acorns dropped by pigeons and pheasants, and elsewhere seedlings of ash and sycamore have come up in similar circumstances.

In the older acquired woodlands the sycamore is invading vigorously, and in some instances forms an understudy to oak and Scots pine. This invasion of the young coniferous plantations by broadleaved species, now beginning, is of great interest, and it is probable that in future rotations the proportion of hardwoods will increase steadily by natural means unless controlled by the forester.

In the King's Forest, areas adjoining standing plantations have been left unplanted in the hope that they will be stocked by natural means, and this hope is already being realized to some extent. Seedlings of pine seem to come up successfully through a grass sward.

Generally speaking, there should not be much difficulty in the future in obtaining natural regeneration of the common conifers and of some hardwoods, except where there is bracken.

To summarize, the plantations of Scots pine and Corsican pine have everywhere been successful. On the poorer lichen-covered land on recent blown sand, the Scots pine grew very slowly at first, and not until the individual trees came into contact with each other to form a light canopy did the growth become normal. The Corsican pine have grown much more slowly in frost hollows than on relatively frost-free sites, but there is no reason to think that once they have reached a sufficient height they will not begin to grow equally well. Douglas fir planted in the open on *Calluna* ground has proved a failure, but it has been more successful on bracken and old arable land although everywhere damaged repeatedly by frost. Experience tends to show that it is inadvisable to plant Douglas fir pure on open land, but that if it is mixed with a species such as Scots pine, the nursing effect of the latter may after a few years enable the Douglas fir to develop. An interesting example of this may be seen at Swaffham, where Douglas fir was repeatedly cut back by frost until Scots pine, which had seeded amongst them from a neighbouring belt, grew sufficiently to afford the necessary protection. Since then the Douglas fir have grown normally. European larch, like Douglas fir, is also uncertain as it appears sensitive to drought as well as to frost. For this species, careful planting and a selection of good plants would seem to be essential.

Oak on the better soils, and especially on land which has recently been arable, promises to grow reasonably well, but it is advisable to provide a nurse species unless natural shelter is available. For this purpose, Scots pine is the most suitable species, but it must be carefully watched as it outgrows the oak in the first few years and may smother it completely unless it receives timely attention.

Beech, for which many of the soils are well suited, has proved much more

difficult, and the problems attached to its establishment are still far from solution. It is sufficiently clear, however, that to plant it in the open, even with a nurse species, is a speculative undertaking, and it might prove better to wait until the pine are large enough to permit of its introduction by underplanting. The experiments at present being conducted by the Research Branch of the Forestry Commission will doubtless throw light on this difficult subject.

Poplar has been used as a backing to some of the roadside hardwood belts and for planting in some of the moister areas near the river. The results have

TABLE VII. *Areas Planted*

	Thetford.	*Swaffham.*	*King's.*
1922	356	106	..
1923	563	315	..
1924	851	295	..
1925	2,138	608	..
1926	2,864	1,183	..
1927	3,696	678	..
1928	3,527	610	..
1929	2,406	378	..
1930	844	425	..
1931	2,486	59	..
1932	2,032	46	..
1933	1,622	20	..
1934	1,376	..	..
1935	1,218	21	..
1936	621	121	633
1937	736	186	625
1938	772	198	556
1939	707	222	870
	28,815	5,471	2,684

varied, but it may be said that it has succeeded where the planting stock was strong and well grown; but where the plants were weak and spindly the results have been poor. Most of the planting has been carried out with rooted plants, but during the last two years, unrooted sets have been tried with a measure of success.

Table VII shows the areas planted at each of the three forests since the work began.

NURSERIES.

There are four nurseries at Thetford, one at King's, and one at Swaffham, with a total area of 88 acres, and these supply most of the requirements for local planting. The soils are light sands with some flints, over the chalk, which in two of the nurseries comes near to the surface, and are easy to work at all seasons. Costs of operations are, therefore, low. These soils, however, are deficient in humus, subject to drought, and liable to wind-blow in the spring, with disastrous effects on newly sown beds.

The risk of drought in the spring makes it advisable to complete lining out and seed sowing at an early date, although, as in 1938, when the drought sets in sooner than normal, the results of early sowing are not altogether satisfactory. The risk of blowing of the soil in dry weather in the spring is being reduced by the planting of hedges in the different nurseries, and one of the most satisfactory plants for this purpose is the common broom, which grows rapidly and lasts for 7 or 8 years. It is usually raised by direct sowing, basic slag being added to stimulate the growth.

Farm-yard manure and leaf-mould are applied regularly to the soil, and artificial manures are used to a limited extent. Green-cropping is not regularly pursued on account of the difficulty of obtaining a satisfactory green crop in dry seasons, but when it is attempted, mustard or blue lupins are the species sown. Instead of green-cropping, a bare summer fallow is often taken, and this allows of the thorough cleaning of the ground.

PROTECTION.

Fire. This constitutes the most serious danger to the safety of the plantations in the Thetford district, and a somewhat elaborate system of fire protection has become necessary for the detection and control of forest fires. Various factors combine together to make the plantations at Thetford peculiarly liable to damage by fire, and among these are low rainfall throughout the year, low atmospheric humidity, a rapidly draining soil, strong winds in the spring time, high temperatures in the summer, and an extensive, unbroken mass of coniferous plantations which burn with great readiness when conditions are suitable. A main railway line, running for about seven miles through the main block of the forest, adds seriously to the risk.

For the prompt detection of forest fires there are five outlook towers at Methwold, High Ash—Didlington, Roudham Heath, High Lodge—near Brandon, and Shakers Lodge—on the Elveden beat. Four of these towers are 50 feet in height and one, at High Lodge, 40 feet high, and they cover adequately the whole of the planted area in the district. They are always manned at periods of danger, and the telephone installation with which each is fitted enables reports to be rapidly transmitted to the district office at Santon Downham, where arrangements are in force for dealing with outbreaks of fire.

The protective measures and fire-fighting arrangements are generally similar to those described by Ryle (8) in a recent article in this journal. Ploughed fire-traces along the roadsides and ploughed strips parallel to the railway line, together with rides kept free from vegetation by ploughing in the main blocks of forest, are the principal means of defence against ground fires and fires in young plantations which have not yet reached the thicket stage. Where the plantations have formed a canopy or are doing so, the danger of crown fires becomes more acute, and, as a precautionary measure, the trees along the edges of these plantations are brashed up to a height of about 6 feet. Generally, the three outside rows of trees are treated in this way, but in dangerous situations all the trees on a strip half a chain or even one chain

wide may have their lower, dead branches removed. The removal of these inflammable dead branches is a measure which undoubtedly adds to the safety of the forest. In plantations at this stage, it is highly important to have suitable means of rapid access in the event of fires, and at the present time access roads are being made fit for motor traffic, while paths have been cut in different directions through the compartments. The latter are of value in allowing a close approach to a fire and at the same time in permitting rapid withdrawal of fire-fighters if the conditions become too dangerous. During

TABLE VIII. *Fires. Thetford Forest*

*Forest year.**	*Number of fires.*	*Area burnt, acres.*
1931	64	7·1
1932	126	29·2
1933	185	219·8
1934	179	39·2
1935	180	16·8
1936	37	2·6
1937	60	1·3
1938	120	147·5

* Forest Year 1931 began on 1 Oct. 1930 and ended 30 Sept. 1931.

recent months a water tank fitted with a pump and a tool chest, both designed to be drawn by car or motor lorry, have been constructed and will be used in fire-fighting.

Fires are possible in the Thetford district at all seasons of the year, and wet weather is not always a complete safeguard, because there have been cases in which a continuous night's rain, ceasing in the morning, has been followed by a fire before midday. The principal danger periods are, however, in the late winter and spring when the dead vegetation is exceedingly inflammable and high winds are usual, and again in the late summer, particularly in spells of hot weather. At any season of the year, however, a week without rain is sufficient to make conditions dangerous. Table VIII gives some details of the number of fires in Thetford Forest during the last eight forest years. The area burnt refers only to plantations destroyed and does not include unplanted land of which a good many acres have been burned over.

The three drought years, 1933, 1934, and 1935, stand out by reason of the large number of fires which occurred, but on the other hand wet seasons like 1936 and 1937 had relatively few fires which did little damage; 1938 with its abnormally dry winter and spring was a bad fire year, though there was little loss during the summer. The largest fires during the period covered by this table were one of 202 acres in 1933 and one of 74 acres in 1938. It will be noted that most of the fires have been restricted to quite small areas, and it is of interest to record that more than 80 per cent. of all fires have been caused by sparks from railway engines.

Animals. The chief animal pest in the district is the rabbit which, finding favourable conditions in the dry climate and open, sandy soil, occurs in great numbers on all the heath and waste land in the neighbourhood. Some idea of the rabbit population in the district may be gathered from the returns of rabbits caught at the King's Forest since the middle of 1935, when entry was first obtained to that area. Between May and the end of September 1935, 4,206 rabbits were killed; in forest year 1936, 27,626 were taken; in 1937, 35,497, and in 1938, 14,983. This gives a total during $3\frac{1}{2}$ years of 82,312 rabbits. The whole area of this forest is a little less than 6,000 acres, of which about half had been enclosed and cleared by the end of September 1938. The rabbits on the unenclosed portion have been reduced in numbers, but are still by no means scarce. The presence of rabbits in such numbers on the open land adjoining the plantations means that fences must be maintained in good condition and constantly patrolled. This necessitates a heavy annual expenditure.

The brown hare is found in some numbers in young plantations before they reach the thicket stage and is a troublesome animal because it cannot be kept out by the ordinary rabbit fence. It is particularly fond of broadleaved plants, especially beech, and its depredations have done much towards keeping back plantations of this species at Thetford. As a result of intensive efforts, its numbers are now declining, but during the years 1936, 1937, and 1938 the hares caught at Thetford numbered 1,378, 919, and 648 respectively.

Roe deer, which were introduced into this district more than 40 years ago (11), have found in the developing plantations the seclusion they require, and they have increased so rapidly within the last few years that special measures have had to be taken to control their numbers. They do little damage to the common pines, although they are partial to species such as Douglas fir, Japanese larch, and *Pinus contorta*, but they browse the broad-leaved species heavily. One or two red deer, escapes from a neighbouring park, are also present.

Mention may be made of the mole which occurs in great abundance in the derelict agricultural land at Thetford and is a source of annoyance and loss on newly planted areas. The moles, working underground, follow the planting lines and by tunnelling under the newly planted stock loosen the plants and by throwing up heaps of earth very frequently bury them altogether. Where moles are abundant, it is inadvisable to use small plants such as 1×1 Corsican pine as these are certain to be either buried or thrown out of the soil. It is not quite clear why moles should be so eager to seek out the spots where plants have been inserted, but they are very quick to do so and they have been known to be at work at one end of a row of plants before the man who was planting had reached the other.

Insects. The most important insect pest is, undoubtedly, the Pine Shoot Moth, *Evetria buoliana*, which has been at work in the plantations of Scots pine since afforestation commenced in 1922. A full account of this insect and its work in East Anglia, based on a survey carried out several years ago, was published by the Forestry Commission as a Bulletin (5) in 1936. That survey revealed a

rather serious state of affairs in certain plantations, but at the same time it showed that a considerable number of the damaged trees made a good recovery from the attack, and it also indicated that attacks were developing more slowly at the time of the survey than they had been several years previously. Within the last few years there is no doubt that the attacks of this insect have become progressively less severe, and it is possible that some form of equilibrium is gradually being reached between the pest and its environment. The plantations which had been damaged have, in most cases, improved considerably, and the pessimistic view which not unnaturally was taken when the attacks were at their height has not in the end been justified. Nevertheless, in all the plantations of Scots pine there exist, in varying numbers, damaged and misshapen trees, the presence of which are, to some extent, a menace to the well-being of the crop as a whole. The Corsican pine plantations are almost entirely free from damage by this insect, but *Pinus contorta*, of which there are some experimental plots at Thetford, has been very severely attacked.

The Pine Sawfly, *Lophyrus pini*, has attacked the younger Scots pine plantations from time to time without doing serious damage, and this is true also of the pine *Lachnus*. Neither insect is abundant at the present time.

The plantations have not yet reached the stage at which control of bark beetles becomes a major problem, but the large programmes of thinning which will be inevitable before many years have passed will make this one of the most difficult questions in the management of the forest.

Fungi. Among fungi, the species which causes most damage in young plantations is *Fomes annosus*. This fungus is apt to be severe on young trees planted on the site of former woodland, and new plantations formed on the site of old belts are often decimated. The young trees are not usually attacked before they are about 2 feet in height, but between this stage and the formation of canopy losses may be severe and conifers of all species may be killed. Beech is also attacked by *Fomes*, but oak does not seem to suffer. It is unusual to find trees killed by *Fomes annosus* after they have formed canopy. This species is, however, responsible for much of the heart-rot which occurs when the trees are older (6). In the Thetford district, larch is one of the most susceptible species to this disease, and most mature trees of this species, as well as many of the younger pole woods, are affected in varying degrees by heart-rot. Spruce also is subject to heart-rot, but it is not unusual to find mature spruce of considerable size which are perfectly sound when felled.

The death of trees in young plantations, caused by *Paxillus giganteus*, has been investigated by Peace (7). This fungus, one of those causing fairy rings, did considerable damage during the drought years of 1933–5, but has been much less prominent recently.

THINNING.

In the oldest of the Scots pine plantations at Thetford and Swaffham, the problem of finding a suitable form of thinning treatment has already arisen. This problem is exceedingly complex. On the most favourable sites, these

young crops have now reached a height of about 25 feet and the dominant trees are making shoots of between 1 and 2 feet in length annually. This active crown development has led to intensive competition among the individual trees, and the stage has already been reached in many areas when treatment has become necessary to control and improve the crop. The problem of treatment is partly silvicultural, partly economic, and partly protective.

In the plantations of Scots pine, which had been attacked by the Pine Shoot Moth, many of the damaged trees, with misshapen stems and wide-spreading crowns, soon acquire the characteristics of 'wolf-trees' and threaten trees of better type in their vicinity. If these 'wolf-trees' were allowed to develop, the effect on the crop as a whole would be unfortunate, and their removal is, therefore, necessary at an early stage. This led to the operation which is known locally as 'pre-thinning', in which plantations which had formed canopy but were not yet ready for thinning were entered, and from them the worst of the 'wolf-trees' were felled and removed. In order to obtain access and to aid in the selection of trees for removal, racks were cut by brashing every third row of trees. The number of trees removed varied from 40 to 60 per acre.

Pre-thinning had an immediate beneficial effect, but the growth of the crop made it obvious that in spite of this treatment the first thinning would have to follow after a very brief interval. That being so, there would seem to be no very great advantage, apart from the immediate relief given, in pre-thinning after canopy had been formed, because it might just as well be combined with the first thinning, either by delaying the pre-thinning, or by advancing the date of the first proper thinning. It was felt, therefore, that in order to obtain the full benefit from a pre-thinning, it ought to be carried out much earlier, before the canopy had formed, but after the main attack of the insect had spent itself. At the present time, younger plantations are being dealt with in which wolf-trees are being removed from crops 12 to 14 feet in height.

The early thinnings, as distinct from pre-thinnings, will raise problems in this and other similar forests, and the principal difficulty will arise from the scale on which the operations will have to be conducted. A thinning programme of, say, 1,000 acres a year involves a vast amount of work in preliminary brashing, in marking the trees for removal, in felling and extraction, and in the subsequent disposal of the produce. It can be said at once that conventional low thinnings, either light or heavy, will be impossible in practice, and the solution would seem to lie in the development of some form of selective thinning. In other words, the object must be to obtain the maximum beneficial effect with the removal of the minimum number of trees, and the trees removed should, when possible, be capable of yielding usable or saleable produce. At the present time, tentative attempts at evolving some such method are in progress. Racks have been cut as in pre-thinning, and 250–350 trees per acre have been selected and permanently marked for retention. Trees of the dominant and co-dominant classes which were oppressing the selected stems and hampering their development were removed, but all the smaller trees were left standing. This has given relief to the selected trees and at the same time

has yielded in produce a number of poles which is not too great to handle. It is proposed to leave the smaller trees to die, and it is realized that this may lead to increase in the population of bark beetles, although it is not known how serious this may be, because there appears to be a conflict of opinion among the entomologists on this point. The other danger inherent in this policy is that it prolongs the period of serious danger from fire as only one-third of the crop is brashed. This danger may be reduced to some extent by brashing all the trees round the boundaries of each compartment.

UTILIZATION.

The produce from the pre-thinnings in Scots pine has been cut into pit-props, fencing stakes, and firewood. These would seem to be the principal outlet for the first thinnings, but if these are on a large scale the principal problem will be to find a market for material below the pit-wood size. The small poles of Scots pine are not straight enough and taper too rapidly for rustic and similar work, but this will not apply to poles of the same size from Corsican pine plantations.

Mature timber of Scots pine from old belts and plantations sells readily to local merchants. Much of it is cut up into fencing material.

OTHER UTILIZATION OF LAND.

At Thetford 2,775 acres are let on agricultural tenancies at rents of £20 and over, while 320 acres are let at rents below this figure. The latter does not include the Forest Workers' Holdings of which there are 164 at Thetford and 24 at Swaffham, occupying areas of 2,207 acres and 178 acres respectively. In addition about 1,700 acres at Thetford have been let on various tenancies while awaiting planting.

Where the Commission own the freehold of the land, the sporting is generally let. The revenue from sporting rents is not as great as it was, but in 1938 the yield from this source amounted to 25 per cent. of the yield from forest produce. This proportion will inevitably become less as the revenue from sales of produce increases.

EMPLOYMENT.

The maximum number of men employed at Thetford during 1938 was 204 and the minimum 152; at Swaffham the corresponding figures were 38 and 25, and at King's 41 and 8. At the last-named forest, which is a recent acquisition, the work is seasonal and the large planting programmes require numerous extra workmen. At Thetford and Swaffham, the position is more stable because the older plantations are able to absorb labour when work at planting and weeding is not available, and many of the regular workers now receive almost full-time employment. Taking the average of the figures given above, the labour employed is equivalent to one man per 162 acres planted at Thetford, and per 172 acres at Swaffham.

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THE MYCORRHIZAL HABIT IN RELATION TO FORESTRY

III. ORGANIC COMPOSTS AND THE GROWTH OF YOUNG TREES[1]

BY M. C. RAYNER

Synopsis

I. INTRODUCTION.
(*a*) Composts: review of previous work; nutrients and dosages employed.
(*b*) Effects of phosphatic manures.
(*c*) Specificity of compost effects.

II. EXPERIMENTAL.
(*a*) Methods and plan of experiments.
(*b*) Results.
(*c*) Analysis of results.
(*d*) Mycorrhizal responses.

III. DISCUSSION OF RESULTS.

IV. SUMMARY.
LITERATURE REFERENCES.
DESCRIPTION OF PLATES.

I. INTRODUCTION.

Composts. Remarkable growth responses by seedlings of pine and other conifers following addition of organic composts to certain poor heath soils were reported in a paper published in this journal in 1936 (5). The experimental use of these composts was prompted by a conviction that the inhibition of growth and suppression of mycorrhiza-formation observed in the soil in question are not simple reactions to poverty of nutrients on the part of the experimental seedlings, but are provoked by profound disturbance of their normal metabolism due to aberrant soil conditions. The conclusions reached, with the evidence on which they were based, have been fully discussed elsewhere (5).

The composts are made by expediting fermentation of materials such as straw, sawdust, or hop waste by addition of 1 per cent. nitrogen (calculated on dry weight) in various forms when making up the heaps. Of those now under consideration, one, C 5, is made from hop waste with addition of 1 per cent. nitrogen in the form of dried blood; the other, C 1, from chopped wheat or oat straw composted similarly with addition of sufficient water to consolidate the

[1] Part I was published in *Forestry*, viii (2), pp. 96–125, and Part II in *Forestry*, x (1), pp. 1–22.

heap. When ready for use, both composts contain appreciable amounts of nutrients; in particular, the nitrogen and phosphoric acid values for C 5 are relatively high. The published analyses give the following percentage values for nitrogen, potash, and phosphoric acid in the two composts in question:

TABLE I.

	C 5.	*C 1.*
Potassium oxide (K_2O) . .	0·75	1·04
Phosphoric acid (P_2O_5) . .	2·80	0·77
Total nitrogen . . .	4·64	3·33
Ammonium salts . . .	0·21	absent
Nitrate nitrogen . . .	0·15	0·43

These values are subject to small variations in successive annual batches of composts, due to fluctuation in the content of the raw materials and other causes (5).

I am indebted to Dr. Robertson, formerly of the Macaulay Institute for Soil Research, Aberdeen, for a further series of analyses and for calculations of the amounts of directly available nutrients in the composts estimated on a basis of Mitscherlich test experiments with oats. It was calculated that the two composts, C 5 and C 1, each applied at the rate of 10 lb. per square yard —the amount used in field experiments—would supply to a crop available nutrients as shown in the following table.

TABLE II. *Available nutrients in lb. per acre contained in composts applied at the rate of 10 lb. per square yard.*

	N.	K_2O.	P_2O_5.
C 5 . . .	71	14	40
C 1 . . .	16	65	17

Since these amounts cannot be regarded as negligible, the view previously expressed that the action of the composts on tree growth 'differs essentially from that of manures containing significant additions of available nutrients' (5, p. 20) calls for direct experimental proof to reinforce the support derived from a considerable body of circumstantial evidence. Before dealing with experiments designed to serve this purpose, it may be useful to recall certain field observations that indicate the complex nature of compost action.

Effects of Phosphatic Manures. For example, it is of interest to note that effects similar in kind to those brought about by compost treatments follow also the use of certain phosphatic manures, especially basic slag, on the soils in question.

The comparative effects on root and shoot growth and on mycorrhizal activity in field sowings of Corsican pine resulting from the use of two composts

and of basic slag are recorded in the photographs now reproduced (Pl. I, figs. 1–4). In all cases the treatments were applied to patches 12 inches by 15 inches at the rate of 2 lb. of compost or 2 oz. of basic slag per patch at the time of sowing. While the improvement in growth is very marked in the plants receiving phosphate, it does not compare in magnitude with that resulting from the use of composts C 5 and C 1, especially the former. It is, however, open to question whether the marked improvement associated with an increased supply of phosphate in the form of basic slag is a direct effect on growth; possibly, as diagnosed for composts, the action is mainly indirect, depending on changes in the microbiological activities of the soil and the humus products resulting from them. The relative degree of permanence in the growth reactions induced by phosphate and compost treatments respectively, with details of the induced mycorrhizal activities, are engaging attention.

Specificity of Compost Effects. A further point of interest is the dissimilarity of response evoked by two closely similar composts in certain species of pine but not in others. In the case illustrated, two sawdust composts of closely similar composition were applied to field sowings of Scots pine (Pl. III, fig. 13). One of these (C 6 a) is made from softwood sawdust and fallen birch leaves in the proportion of 75 per cent. to 25 per cent. dry weight; the other (C 6 b) from softwood sawdust and chopped straw in the same proportions. Both were composted with 1 per cent. nitrogen in the form of dried blood over a period of $5\frac{1}{2}$ months.

The seedlings treated with C 6 a have made well-balanced and vigorous growth with free development of mycorrhizas of normal structure; those treated with C 6 b are little better than the untreated controls, and show a similar type of inhibited root development with few mycorrhizas having structural peculiarities similar to those in mycorrhizas of control plants (see p. 31). Corresponding sowings of *Pinus contorta* were in surprising contrast, the seedlings showing only negligible differences of size and vigour as a result of the same two treatments, both of which produced improvement of growth as compared with that of the controls.

In view of the general agreement in amounts of soluble nutrients shown by chemical analyses and the resemblance of the two composts in physical character, it is reasonable to interpret their differential action as depending on differences in organic constitution and microflora at the time of application. Accepting this view, it follows that such differences operate within extremely narrow limits in modifying growth in coniferous seedlings, different species often responding very differently. In non-woodland soils such as that under discussion, the nature and fate of the organic residues present are, therefore, more critically related with growth of conifers—probably with that of trees in general—than are inequalities in the amounts of available mineral nutrients.

It is the purpose of the present communication to place this hypothesis respecting the nature of compost action on a more secure experimental basis. The experiments about to be described were designed with this end in view.

II. EXPERIMENTAL.

Methods and Plan of Experiments. In order to analyse the growth effects produced by the addition of composts to the experimental soil, the method of comparative pot cultures with transported soil was used. In two series, compost was added direct to the potting soil at sowing; in two others the estimated amounts of salts to supply equivalent values for nitrogen, potash, phosphoric acid, and lime in the amount of compost present were added to each pot as soon as the seedlings were growing freely. A control series contained the experimental soil without addition. All series were run in duplicate: in one group the pots stood in glass containers covered with dark paper and drainage water was returned regularly; in the other group, drainage water was not returned to the pots (Pls. II and III, figs. 1–12). Each series included 12 pots; in each pot 20 selected seeds of Scots pine were sown in March 1937. When the plants were well established, the number of seedlings per pot was reduced to 9. All pot cultures were grown in a special shelter house and were watered with rain-water throughout the experiment.

For independent comparison and reasons of general interest, two additional series were included: in one, similar sowings were made in humus from a good stand of Scots pine in a relatively favourable soil of similar type from the New Forest; in the other, in the experimental soil plus an addition of old cow manure, corresponding in amount to that of compost per pot. Since the hypothesis to be tested involves the assumption of mycotrophy in pine, and no mycorrhizal activities could be expected for some months after germination, the cultures were planned to extend over two growing seasons.

The following is a complete list of the experimental series:

1. Control, Wareham soil untreated.
2. Wareham soil + C 5 compost (C 5).
3. „ „ + equivalent salts of C 5 compost (C 5 salts).
4. „ „ + C 1 compost (C 1).
5. „ „ + equivalent salts of C 1 compost (C 1 salts).
6. „ „ + cow manure (C.M.).
7. Extract of C 5 compost.
8. „ „ C 1 compost.
9. „ „ cow manure.
10. Scots pine humus (N.F.).

The compost extracts and that of cow manure were prepared as described on p. 24. That made from cow manure was definitely deleterious to health and growth of the seedlings, and this series was discarded.

The amounts of salts supplied to the pots in series 3 and 5 receiving equivalent nutrients were calculated from figures kindly supplied by Dr. Robertson of the Macaulay Institute for Soil Research, as shown in Table III. The calcium content of C 5 and C 1 were also calculated, the values found representing approximately 8 gm. and 4 gm. of lime (CaO) per 250 gm. of dry compost respectively. As in pot experiments generally, the amount of compost added to the experimental soil was at the rate of 1 part of compost to 3 parts of

soil, this being regarded as roughly comparable with the 'dilution effect' obtained by the dressings used in the corresponding field experiments. On this basis, the dry weights of composts required for each experimental series was 231·5 gm. of C 5 (oven-dried) and 240·8 gm. of C 1 (oven-dried) per 12 pots,

TABLE III. *Available nutrients per 250 gm. compost (air-dried).*

	N.	K_2O.	P_2O_5.
Series 3 (salts of C 5 compost) .	1·45 gm.	0·30 gm.	1·00 gm.
Series 5 (salts of C 1 compost) .	0·38 „	1·30 „	0·35 „

or roughly 20 gm. per pot. Using the values for available nitrogen, potash, and phosphoric acid set out in Table III, there will be required, therefore, for the 12 pots of series 3 (receiving equivalent salts of C 5), and for the 12 pots of series 5 (receiving equivalent salts of C 1) the following amounts:

	Series 3 (C 5 salts).	*Series 5 (C 1 salts).*
N	1·34 gm.	0·35 gm.
K_2O . . .	0·27 „	1·25 „
P_2O_5 . . .	0·96 „	0·33 „

The nutrients were given as ammonium nitrate (NH_4NO_3), potassium sulphate (K_2SO_4 anhydrous), and sodium diphosphate (Na_2HPO_4 anhydrous), as supplied by British Drug Houses Ltd. for analytical purposes, there being required for the 12 pots of series 3, 3·83 gm. of NH_4NO_3, 0·49 gm. of K_2SO_4, and 1·92 gm. of Na_2HPO_4, and for the 12 pots of series 5, 1·03 gm. of NH_4NO_3, 2·3 gm. of K_2SO_4 and 0·66 gm. of Na_2HPO_4. These salts were used in two solutions applied at the rate of 25 c.c. per pot as follows:

	Solution for series 3.	*Solution for series 5.*
NH_4NO_3 . .	12·8 gm.	3·4 gm.
K_2SO_4 . . .	1·6 „	7·6 „
Na_2HPO_4 . .	6·4 „	2·2 „
Distilled water .	1,000 c.c.	1,000 c.c.

It will be observed that the equivalent amounts of nitrogen and phosphoric acid are relatively high in compost C 5, and the equivalent amount of potash relatively high in compost C 1. By similar calculations from the figures supplied for the lime content of C 5 and C 1, each pot of series 3 required 1·1 gm. (1 gm.) of $CaCO_3$ and each pot of series 5 required 0·56 gm. (0·6 gm.) of $CaCO_3$.

The composts were mixed with the soil at sowing, and the equivalent salt solutions given in one dose per pot when the seedlings were emerging from the seed-leaf stage and making active root growth. The amount of solution was

just sufficient to moisten the soil without draining through it. The calcium carbonate supplied was powdered uniformly on the surface and worked in with a glass rod at the time of sowing.

Series 7 and 8, receiving C 5 extract and C 1 extract respectively, were actually constituent parts of another pot experiment carried on simultaneously and designed to test the conclusions of Niklewski in respect to the effects of 'soluble humus' as set out in a recent publication (2). The extracts were prepared by the method used by Niklewski for extracting organic manures as follows. Composts C 5 and C 1, in amounts corresponding to those added to the pot cultures in series 2 and 4, were extracted in distilled water. After standing for 24 hours, the water was decanted, and by repeating this process 7 times a series of extracts was prepared progressively poorer in soluble mineral salts but containing, on the Niklewski hypothesis, a relatively high proportion of active 'soluble humus'. That part of this experiment included in the present records was the eighth extraction after seven decantations. Estimation of the contained salts of this extract by chemical analysis and of the 'soluble humus' by the Niklewski method gave the values shown in the following table:

TABLE IV. *Content per litre of eighth Niklewski decanter.*

	C 5.	*C 1.*
Total nitrogen . . .	0·023 gm.	0·020 gm.
Ammoniacal nitrogen . .	0·0002 „	0·0005 „
Nitrate nitrogen . .	0·018 „	0·009 „
Potassium (K_2O) . .	0·012 „	0·07 „
Phosphorus (P_2O_5) . .	0·020 „	0·006 „
Calcium (CaO) . . .	0·059 „	0·045 „
Water-soluble humus . .	0·22 „	0·35 „
pH	6·9	7·0

The extracts were supplied to the plants in doses of 25 c.c. per pot, beginning 3 months from sowing when the seedlings were growing freely and repeated once weekly over a period of 4 weeks.

The experiment planned to test the Niklewski hypothesis when applied to the two composts C 5 and C 1 gave inconclusive results. That part of it included in the records set out in Table IV shows that the amounts of contained salts were negligible. Whether the slight and irregular stimulation of growth observed was brought about by 'soluble humus' as defined by Niklewski or by solutes of unknown nature, as, for example, auxins or vitamin B 1, is at present a matter of conjecture.

Results. The cultures were entirely satisfactory in respect to health of the seedlings, uniformity of growth within each series, and range of variation within the populations of individual pots. The photographs reproduced are, in each case, representative for the 12 pots of the series to which they have reference.

At the end of the first year's growth the results may be summarized as follows:

1. Control seedlings in untreated soil made defective root and shoot growth and produced short needles of bad colour. Although the tendency to go into check is always marked in the first season, the deleterious effects of this soil are progressively decreased in pot cultures as compared with field plots owing to leaching and improved aeration; nevertheless, the plants contrasted sharply with those in series 10, growing in a favourable Scots pine soil (Pl. II, fig. 5; Pl. III, fig. 11).

2. Seedlings in series 2 and 4, receiving composts C 5 and C 1 respectively, were larger and of more uniform and vigorous growth than the controls. Shoot and root development were greater, needles longer and of better colour, these features being more marked in the plants receiving C 5.

3. Seedlings from series 3 and 5 receiving equivalent salts grew well and were quite healthy and vigorous, but at the end of the growing season were smaller than the plants of either composted series (Pl. II, figs. 1–4).

4. As judged by examination of the growing plants at the end of the first year's growth, the regular return of drainage water from the pots produced surprisingly little effect (see p. 27). On the whole, the plants of all series with drainage *not* returned, with the possible exception of those receiving composts, were slightly better than those in the corresponding series with drainage returned, this applying equally to controls and treated plants. Study of the roots in respect to mycorrhizal development was postponed until later.

All experimental series continued to make satisfactory growth throughout the second season, the differences between pots receiving composts and those receiving equivalent salts becoming more marked as the summer advanced. The photographs illustrate the condition of the cultures towards the close of the second season's growth (Pl. III, figs. 7–12).

By October 1938, changes affecting not only the size but also the health and vigour of the plants in the comparative groups receiving and not receiving returned drainage had become apparent. In respect to this the condition of the plants as a whole at the close of the second year's growth was as follows. In the two control series there was a difference of size in favour of those not receiving drainage. In seedlings of the four series receiving composts, the differences in any given series were inappreciable; in those of the corresponding four series receiving equivalent salts, the superiority of plants not receiving returned drainage was well marked, while definite symptoms of bad health appeared for the first time in those of the other group, expressed not only in size but also by dull purpling of the needles and shrinkage of the winter buds. These differences are reflected in the final dry weights (Table V) and are analysed in the accompanying graphs (Text-figs. 1–3). The cultures were brought to an end in December 1938, and the dry weights of the plants determined, shoots and roots being weighed separately. Shoots were cut to soil level and roots carefully washed free from soil in running water after soaking; they were then oven-dried at 60° C.–65° C. until they ceased to lose appreciable weight.

TABLE V. *Group I. Drainage returned.*

Series.	*Treatment.*		*No. of plants.*	*Weight in gm.*		*Mean weight per 100 plants.*	
Series 1.	Control	Shoots	79	10·56	15·73	13·36	19·90
		Roots		5·15		6·54	
„ 2.	+C 5	Shoots	38	49·02	65·27	129·00	171·76
		Roots		16·25		42·76	
„ 3.	+C 5 salts	Shoots	61	30·70	43·05	50·32	70·56
		Roots		12·35		20·24	
„ 4.	+C 1	Shoots	75	63·05	85·32	84·06	113·75
		Roots		22·27		29·69	
„ 5.	+C 1 salts	Shoots	79	17·85	25·72	22·59	32·55
		Roots		7·87		9·96	
„ 6.	+C M.	Shoots	73	69·02	94·39	94·54	129·29
		Roots		25·37		34·75	
„ 7.	+C 5 Extract	Shoots	40	8·65	12·82	21·62	32·04
		Roots		4·17		10·42	
„ 8.	+C 1 Extract	Shoots	40	5·68	8·08	14·20	20·20
		Roots		2·40		6·00	

Group II. Drainage not returned.

Series 1.	Control	Shoots	56	11·95	16·53	21·34	29·52
		Roots		4·58		8·18	
„ 2.	+C 5	Shoots	43	52·07	67·37	121·09	156·67
		Roots		15·30		35·58	
„ 3.	+C 5 salts	Shoots	53	35·97	49·02	67·87	92·49
		Roots		13·05		24·62	
„ 4.	+C 1	Shoots	52	43·40	56·23	83·46	108·13
		Roots		12·83		24·67	
„ 5.	+C 1 salts	Shoots	74	22·98	32·74	31·05	44·24
		Roots		9·76		13·19	
„ 6.	+C M.	Shoots	64	59·42	80·92	92·84	126·43
		Roots		21·50		33·59	
„ 7.	+C 5 Extract	Shoots	33	10·77	14·97	32·63	45·35
		Roots		4·20		12·72	
„ 8.	+C 1 Extract	Shoots	34	9·87	13·54	29·03	39·82
		Roots		3·67		10·79	

Three pots of each series of group I (drainage returned) were retained for repotting and further observations.

As may be judged from the photographs and dry weights, the differences between plants of the critical experimental series 1, 2, 3, 4, and 5 were very large and well outside the range of variation within the series.

Analysis of Results. Inspection of Table V and the text-figures derived from it shows that all treatments give increased absolute dry-weight values as compared with those of the controls. The increase is least with the compost extracts, greater with the equivalent salts, especially, as might be expected, with those of C 5; greatest with C 1 compost, cow manure, and C 5 compost, reaching maximum values in the last-named series.

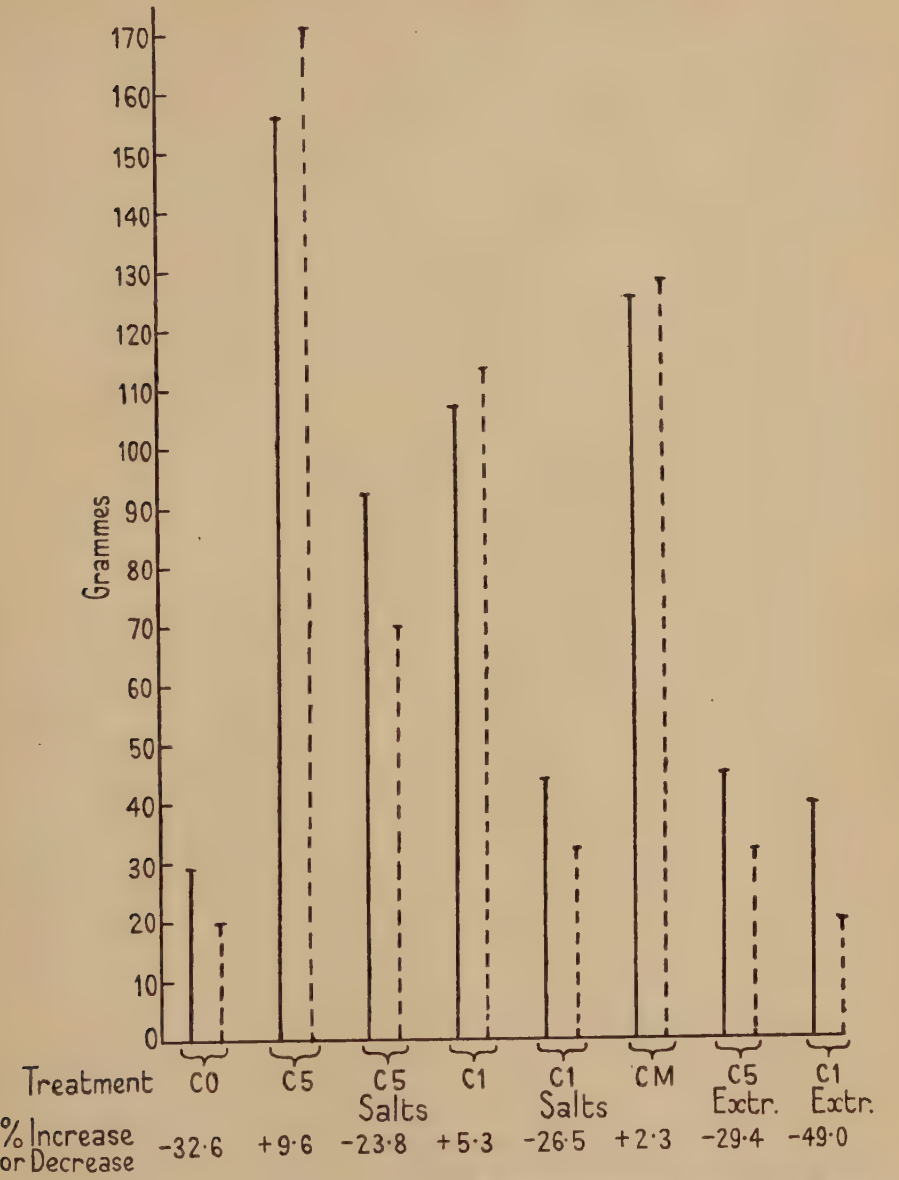

FIG. 1. Total dry weights per 100 plants under 8 different treatments, showing also effect of returning drainage water. ——— drainage water *not* returned; – – – – – drainage water returned. Percentage increase or decrease resulting from drainage return shown at bottom of graph.

Certain points of interest emerge from detailed study of these dry-weight values. Comparing those of group II, drainage not returned, with those of group I, drainage returned, and representing the total dry weight of the

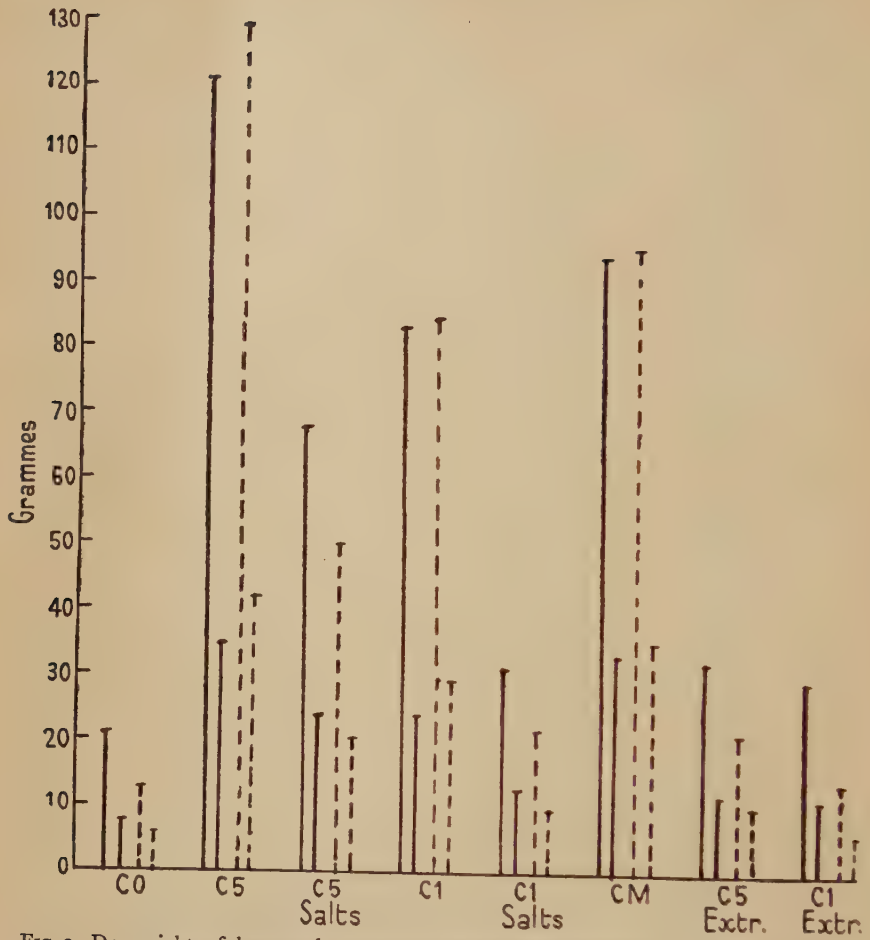

FIG. 2. Dry weights of shoots and roots per 100 plants shown separately. ———— drainage water *not* returned; – – – – – drainage water returned. Shoot values are shown to the left of root values in every case.

former as 100 in each series, the effect of returning drainage water results in a percentage increase or decrease in total dry weight as follows:

Series 1.	Wareham soil, untreated		−32·5	per cent.
,, 2.	,,	,, +C 5 compost	+12·2	,,
,, 3.	,,	,, +C 5 salts	−23·7	,,
,, 4.	,,	,, +C 1 compost	+ 5·2	,,
,, 5.	,,	,, +C 1 salts	−26·4	,,
,, 6.	,,	,, +cow manure	+ 2·2	,,
,, 7.	,,	,, +C 5 extract	−29·3	,,
,, 8.	,,	,, +C 1 extract	−49·2	,,

These values are inserted in Text-fig. 1. The separate effects on shoot and root of the different treatments, with and without drainage returned, are shown graphically in Text-fig. 2. The percentage increases and decreases in

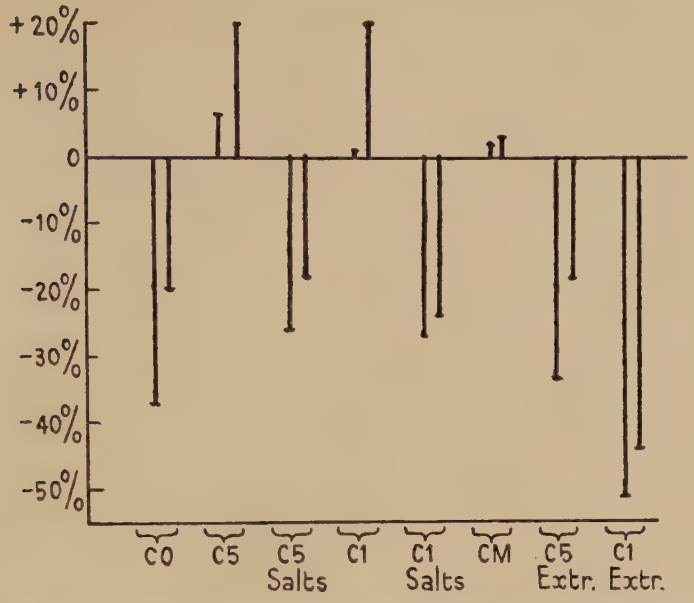

FIG. 3. Percentage increase or decrease in dry weight of shoot and root resulting from return of drainage water. Shoot values are shown to left of root values in every case.

dry weights, expressing the dry-weight values when drainage is *not* returned as 100 in every case are as follows:

Treatment.	*Shoot.*	*Root.*
Series 1. Control (CO) .	−37·3	−20·0
„ 2. C 5 compost .	+ 6·5	+20·2
„ 3. C 5 salts . .	−25·8	−17·8
„ 4. C 1 compost .	+ 0·7	+20·3
„ 5. C 1 salts . .	−27·3	−24·5
„ 6. Cow manure .	+ 1·8	+ 3·4
„ 7. C 5 extract .	−33·7	−18·0
„ 8. C 1 extract .	−51·1	−44·4

These values are shown graphically in Text-fig. 3.

It would appear that in those cases in which return of the drainage water is *beneficial*, the increase in percentage dry weight is mainly in respect to the root system. On the other hand, in all other instances, where the effect of returning drainage is *deleterious*, the decrease in percentage dry weight is most evident in respect to the shoot system. Return of the drainage water is evidently unfavourable in all cases except those in which composts were used, where it becomes beneficial. In the cow manure series there is little effect, but what there is appears to be favourable as with composts.

The presence of soil substances actively inimical to root growth was inferred at an early stage of the Wareham researches (3). It was, indeed, the conclusion

derived from this inference, that the marked infertility of this soil for tree growth is more closely related with the presence of such toxic substances than with poverty of nutrients, that led originally to the use of organic composts as a means of alleviating the unfavourable conditions. The origin, character, and distribution of such toxic substances are now the subject of a special research and the matter need not be considered further here. In view of the purpose of the present experiments, however, it is regarded as highly significant that return of drainage water over considerable periods has provided evidence of a depressing effect upon growth far exceeding in magnitude any beneficial effect derived from return of leached nutrients in all cases except those in which the soil received additions of organic matter in the form of composts or cow manure. The results of the present experiments thus confirm conclusions already reached in respect to the existence of deleterious substances in the soil solution and clarify previous observations on the beneficial effects of leaching in pot cultures. Not only so, but they afford convincing evidence in support of the hypothesis that compost treatments operate mainly by bringing about fundamental changes in the organic residues, whereby the microbiological activities of the soil and their ultimate by-products are profoundly and permanently modified.

The experiments show that increase in the supply of available nutrients plays a relatively insignificant role in the steady maintenance of healthy and vigorous growth that follows addition of composts to the soil. They show further that addition of mineral salts is practically without influence on the production of substances deleterious to growth, whereas that of composts—and to a less extent of cow manure—puts a stop to the production of undesirable by-products, thereby rendering the leachings innocuous and permitting utilization of any nutrients returned with them.

Mycorrhizal Responses. A full account of the mycorrhizal phenomena observed in the course of the Wareham Forest researches and of the mycological details relating to them will be published shortly. It is not proposed, therefore, to describe in detail the mycorrhizal responses observed in these experimental cultures. Inasmuch, however, as such responses are held to provide a valuable index for the estimation of soil conditions favourable or otherwise for the growth of pine seedlings, and since they were well marked in the plants of the pot cultures now under review, a brief summary of the facts regarded as relevant is now included.

The problem of mycorrhizal activity is simplified because mycelial activity in general is more or less inhibited in untreated soil from Wareham Forest and only a limited number of mycorrhiza-formers is known to be present. In the case of Scots pine one only, *Boletus bovinus*, has been observed to form associations in the field or in pot cultures of the transported soil. Another, *Mycelium radicis nigrostrigosum*, has been introduced in humus inocula, but is not known to occur on the experimental area from which the soil for these pot cultures was derived (1, 4).

In control plots of untreated soil mycorrhizas are very scantily developed

owing to inhibiting soil conditions; in pot cultures of the same soil they tend to increase in number with the improvement that follows leaching from continuous watering. That one fungus species only is responsible, and that this species is *Boletus bovinus*, has been established by comparison of pure cultures isolated from sporophores of this fungus with others isolated from mycorrhizas of Scots pine seedlings growing in untreated soil and in soil to which compost has been added. Incidentally, it may be noted that sporophores of this species are produced, often in abundance, in compost-treated plots in which Scots pine seedlings have been growing freely for several years; they have not been observed in control plots of untreated soil with very poor plants. The account that follows applies to mycorrhizas of Scots pine formed by association with *Boletus bovinus* as observed in the Wareham Forest soil.

(i) When seedlings of Scots pine are making healthy and vigorous growth, as, for example, after addition of C 5 or other suitable compost to the soil, the mycorrhizas are pale brown, forked organs of normal ectotrophic structure. Their surface is smooth without conspicuous investment of fungal hyphae in the surrounding soil. Viewed microscopically in transverse section, they exhibit characteristic features: a mycelial mantle of moderate diameter, a well-developed Hartig net between the cortical cells, a conspicuous layer of tannin cells beneath the mantle, and the appearance of dense granular contents in a number of the outer cortical cells. Individual hyphae of the fungus are hyaline and free from excretions.

(ii) Mycorrhizas formed by *Boletus bovinus* in the untreated soil, whether in the field or in pot cultures, invariably show structural peculiarities, the main features of which are as follows: the mantle is greatly increased in diameter with a tendency to form 'tuber' mycorrhizas by coalescence of the mantles of contiguous rootlets; the outer tissues of the root become absorbed in the mantle to an abnormal extent, the tannin layer does not develop or appears very irregularly, and cortical cells with conspicuous granular contents are absent. Surrounding each mycorrhiza or group of mycorrhizas is a conspicuous zone of loose mycelial growth, individual hyphae in which are continuous with those in the mantle. Viewed microscopically, the hyphae, both of the mantles and of mycelium in the soil about them, are covered with droplets of pinky-brown exudate.

These two types of structure are readily recognizable under a lens, that in the untreated soil being easily distinguishable by the conspicuous external zone of mycelial growth and the pinky-brown colour.

Passing now to the mycorrhizal responses shown by seedlings in the experimental cultures. Attention is directed to them because the differences observed are delicately adjusted with changes artificially induced in the soil and closely correlated with variations in growth and general vigour of the plants, thus emphasizing the importance of correct mycorrhizal equipment and the critical part played in this by changes in humus constitution. The character of the mycorrhizal variation is indicated in the photographs and is briefly as follows (Pl. IV, figs. 1–3).

Series 1: *Control plants growing in untreated soil.* Short root development is very defective and few mycorrhizas are formed. Structurally, these belong to the peculiar type already described under (*b*); the mycelial growth surrounding them, conspicuous by reason of the pinky-brown exudate covering the hyphae, is well shown in the photograph (Pl. IV, fig. 1).

Series 3 and 5: *Plants receiving equivalent nutrient salts.* Some stimulation of short root development is evident, especially in the case of C 5 salts. Structurally, a majority of the mycorrhizas resemble those formed by control plants; the external resemblance between these is clearly shown in the photographs (Pl. IV, figs. 1 and 3).

Series 2 and 4: *Plants receiving composts.* There is marked stimulation of short root development and a majority of these are forked mycorrhizas of the structural type found in healthy plants. In external appearance they deviate slightly from the type described under (*a*) owing to pot culture conditions, but are of normal structure as seen microscopically in section. The investment of mycelium conspicuous in series 1, 3, and 5 just described, is absent, and the hyphae are hyaline and free from excretions.

The evidence derived from mycorrhizal behaviour reinforces the conclusions already deduced from comparison of growth increments in the parallel series receiving and not receiving returned drainage. The latter are interpreted as meaning that the deleterious effects produced by returning the drainage water, as expressed by correspondingly low dry-weight values, are unaffected by additions of available nutrient salts sufficient to produce a pronounced improvement of growth, but are removed *permanently* by additions of appropriate organic material. Whatever the exact action of the latter upon the soil, it evidently operates by removing factors inimical to root and mycorrhiza formation, stimulating the development of short roots and their conversion to mycorrhizas, and thus promoting normal growth and vigour of the whole plant in an exceptional degree. The relative abundance of mycorrhizas and their structural features serve, therefore, as very delicate indicators of these soil changes.

III. DISCUSSION OF RESULTS.

The experiments described in this paper were designed to meet the criticism that addition of mineral nutrients to the soil, in amounts corresponding to those in composts, would produce similar effects on growth, and to establish the correctness of conclusions put forward in an earlier communication (5). For the soil under investigation, these conclusions were that the use of organic composts produced qualitative changes in the humus constituents and that these, rather than increase in the supply of available nutrients, are the fundamental cause of restored fertility. The failure of growth and irregularity of behaviour observed in trees were interpreted as bound up with biological activities yielding inimical by-products, and not merely as a resultant of poverty in available nutrients.

The evidence derived from the pot-cultures in series 2, 3, 4, and 5 of the

present experiments affords direct support for this hypothesis of compost action. It proves that increasing the supply of nutrients in this poor soil by the addition of soluble salts of nitrogen, potash, and phosphoric acid, corresponding in amounts to those in the composts, evokes surprisingly little response in pine seedlings, even when potential loss by leaching is compensated by return of all drainage throughout the period of the experiment. It thus provides a complete refutation of the criticism that the action of the composts in promoting the healthy growth of young trees on certain soils is mainly due to increased supply of directly available nutrients, confirming the conclusion that the action of the compost in stimulating the growth of pine seedlings 'differs essentially from that of ordinary manures'.

That the strikingly beneficial effects on the growth of pines and other conifers are closely bound up with the mycorrhizal habit, and the reactions of this on nutrition, may be fairly deduced from the delicacy of response shown by these experimental plants in respect to short root development and from the histological changes of structure induced in individual mycorrhizas. It is already known from researches in progress that profound changes in the microbiological activities of this soil follow the use of composts; the activation of the mycelium of specific mycorrhiza-formers is one of these changes, and the stimulation of mycorrhizal activity observed is an index of such activation and of the changed soil environment that accompanies it. With the possible criticism that there is still no direct experimental evidence that an increased degree of mycotrophic nutrition on the part of the seedlings and the promotion of soil conditions favouring it are vital factors in the differential behaviour of the plants this paper is not concerned, beyond pointing out that in these pot experiments all plants showing maximum size, health, and vigour showed also a maximum development of mycorrhizas. The alternative view to that of beneficent mutualism, now generally accepted, involves the paradoxical assumption that healthy growth is invariably accompanied by decreased resistance to parasitic attack, and by the production of an absorptive system, the major part of which is hampered by fungal interference.

It is not hereby claimed that any and every adverse soil condition, whether for trees or other plants, will be remedied by supplying organic composts of exactly the kind described. It is suggested, however, that the experimental results now recorded clarify those described in the earlier papers of this series, rendering it possible to define more precisely the real nature of the underlying problems. There are raised, moreover, general problems of plant nutrition as significant to the plant physiologist as to the forester. These problems are concerned with the effects of qualitative differences in the organic residues of the soil, with the biological activities underlying them, and with the evolution of new methods by which such activities may be studied and controlled. It is believed that amelioration of the inhibitory conditions, in the special case now under review, by the use of organic composts is effective because this treatment operates as a means of biological control, setting free dormant activities and bringing about profound changes in the organic substrate.

There is a vast and impressive literature concerned with the soil humus. From the standpoint of the plant physiologist, there are still, however, considerable gaps in an understanding of the relations between the chemical and biological changes in humus on the one hand and growth of the higher plants on the other. The exact mechanism of mycotrophy in nutrition, as expressed in the mycorrhizal habit so widespread among vascular plants, is one such gap; others are indicated in the experimental results just described. A clearer understanding of soil fertility in relation to growth of the higher plants is bound up with bridging these gaps in knowledge. That more is required for this than the laboratory study of pure cultures of soil organisms has been emphasized recently by Winogradski, who stresses the need for caution in applying data derived from such studies when unrelated to the activities of the soil population as a whole (*6*).

From the standpoint of practical forestry it is realized that the use of composts, such as have proved effective at Wareham, may not be always justified on economic grounds. The compost method of treatment owed its genesis in part to observations of experimental forestry methods in litter control and the changes in mycorrhizal activities that accompanied them (*5*, pp. 18–20). The success that has attended the use of composts in a special case emphasizes the importance of this matter in the afforestation of non-woodland soils. In the Wareham area, for example, it appears certain that the planting of pure stands of pines and other conifers is likely to lead to undesirable soil reactions. The obvious expedient of interplanting with deciduous species here presents difficulties, since the factors that inhibit growth are operative in greater or less degree in all cases. Initial treatment with composts appears to offer a method whereby mixed planting with deciduous species, with the control of litter constituents it affords, may be successfully attempted and permanent amelioration of soil conditions attained.

This paper affords a welcome opportunity to express my thanks to Mr. G. J. Butler, Superintendent of the Botany Garden, Bedford College, University of London, whose skill and attention have made possible the successful pot culture of conifers and other trees under London conditions. Acknowledgement has already been made in the text to the Macaulay Institute for Soil Research for their co-operation. I must again express my indebtedness to the Forestry Commission of Great Britain for continued financial support.

IV. SUMMARY.

1. With reference to the use of organic composts described in an earlier paper of this series, an account is given of pot experiments designed to analyse the growth effects produced by certain composts.

2. Pot cultures of Scots pine were grown in alternative series supplied respectively with composts and with equivalent amounts of lime and available nitrogen, potash, and phosphoric acid. The results are expressed by photographs of the experimental plants at 6 months and 18 months from sowing, and in a table showing the final dry weights. The experiments show con-

PLATE I

1

2

3

4

5

6

PLATE II

C0
C5
C5
Scots pine
7

C0
C5
C5
Scots pine
8

C0
C1
C1
Scots pine
9

C0
C1
C1
Scots pine
10

C0
N.F.
Scots pine
11

Co
Cna
Cnb
13

C0
CM
Scots pine
12

PLATE III

1

2

3

clusively that increase in the supply of available nutrients plays a relatively insignificant role in the maintenance of healthy and vigorous growth that follows addition of composts to the soil.

3. The results confirm conclusions previously reached in respect to the existence of actively deleterious substances in the experimental soil. They show further that addition of organic composts puts an end to the production of such substances, whereas addition of equivalent amounts of available nutrients as inorganic salts is practically without effect.

4. The bearing of these results on the hypothesis of compost action put forward and the relation of the latter with methods of litter control are discussed.

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DESCRIPTION OF PLATES

PLATE I. Wareham Forest, Dorset. Comparative effects produced by two composts (C 5 and C 1) and basic slag on field sowings of Corsican pine. Photographs of representative patches 17 months from sowing.

1. Control, untreated; 2. Treated 2 oz. of basic slag at sowing; 3. Treated 2 lb. of compost C 5 at sowing; 4. Treated 2 lb. of compost C 1 at sowing.

PLATE II. Figs. 1–6: pot-culture experiments of Scots pine designed to analyse the effects of composts by supplying two composts (C 5, C 1) or their equivalent mineral salts to alternative series, 6 months from sowing. Additional series of controls were grown in a favourable Scots pine humus and in the experimental soil plus addition of old cow-dung corresponding in amount to that of the composts.

The pots of Group I, drainage returned, are shown in the photographs to the left of the plate; the corresponding pots of group II, drainage not returned, in those to the right.

C 0: control, experimental soil untreated; C 5: same plus 25 per cent. C 5 compost; C 5 salts: same plus equivalent salts of C 5; C 1: same plus 25 per cent. C 1 compost; C 1 salts: same plus equivalent salts of C 1; C.M.: same plus 25 per cent. cow manure; N.F.: favourable Scots pine humus.

PLATE III. Figs. 7–12: pot-culture experiments of Scots pine as described for Plate II, 18 months from sowing. Fig. 13: plants of Scots pine from field sowings treated with two composts, C 6 a and C 6 b, of closely similar composition, 17 months from sowing. Control plant on left.

PLATE IV. Fig. 1: Portion of root system from control plant in series 1, in untreated soil; Fig. 2, ditto from plant in Series 4, in the same soil with addition of 25 per cent. of C 1 compost; Fig. 3, ditto from series 5, in the same soil with addition of equivalent salts of C1 compost.

Note greater production of short roots shown in Fig. 2, and conspicuous mycelial investment of mycorrhizas in Figs. 1 and 3. A majority of short roots in Fig. 3 are mycorrhizal; the mycorrhizas are normal in structure, but in external appearance deviate slightly from type due to pot culture conditions.

FOREST PATHOLOGY IN NORTH AMERICA

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THIS short paper is based on a four months' tour of America made in the summer of 1938, in the course of which the author visited 36 of the 48 States in the U.S.A., and three Canadian Provinces. Naturally, in the time available only a very impressionistic view of the pathological situation in American forests could be formed. No attempt will be made here to give a comprehensive account of tree diseases in America; for such general accounts the reader is referred to two recent books (5, 21), and to a number of recently published papers which cover the forest diseases of certain districts or treat certain aspects of American forest pathology (1, 16, 17, 18, 24, 36). A number of American tree diseases will be mentioned in this paper, but only very briefly; for further information, references are given to the most recent and comprehensive papers, many further references will be found in the publications already mentioned (5, 21, 24).

Forest pathology in America is a young but rapidly growing science, with none of the basis of tradition present, for instance, in Germany. In its youthfulness and lack of tradition it is very similar to forest pathology in this country, but the material with which it is concerned and the conditions under which it has to work are very different. American forests are primarily natural and usually mixed, hence they present problems very different from those of the predominatingly artificial and pure forests which we have in Great Britain. On the other hand, America has some concern with nursery and plantation diseases, and work on diseases of natural stands, though not directly applicable to this country, has many lessons to teach us.

Naturally, if regeneration is abundant, there can be considerable losses without any effect on the final crop. Thus minor diseases of young trees, causing the suppression or death of only a few trees, appear to have little importance; whereas in Great Britain diseases affecting the same number of trees would be more serious, because a large gap would be caused in a plantation at normal spacing. So in America emphasis has tended to fall on epidemic diseases such as *Endothia parasitica* (Chestnut Blight), *Cronartium ribicola* (White Pine Blister Rust), and on that ever-present menace to the mature crop, decay. This does not mean that the less spectacular diseases have been neglected; naturally they must be studied lest they increase in virulence, and it is realized that they may greatly affect the forest by rendering one species less able to compete with the other components of the mixed forest.

There is, however, no question that decay is the biggest immediate problem affecting American forests pathologically. In the West, where untouched stands still form a high proportion of the cut, many of the trees are naturally

overmature and the losses due to decay are very high. The importance of decay in the stands now being cut is increased by the fact that they are often in rather inaccessible places—the more available stands already having been logged—and transport costs are therefore too high to allow of partially rotted timber being extracted. This leads to a very large amount of waste, and the amount of timber left lying on a British Columbian felling site would break the heart of many a British forester. In the East there are enormous areas of second- and third-growth hardwoods which have arisen from seed and as sprouts from the original stumps, and here many trees are very badly rotted. The old stump itself is naturally a very ready source of infection in sprout stands (18, 20), and in both classes surface fires—which are very common and kill many young trees—leave wounds on the windward side of larger trees which serve as a means of entry for decay (18, 38).

Where so large an area and so many tree species are concerned, a large number of wood-rotting fungi may be expected. No attempt will be made to enumerate them; further information can be got from certain of the publications listed (3, 10, 18, 20, 24). Many do not occur in this country, but most of our important species, especially those on conifers, do occur in America. It is of particular interest to note here that *Fomes annosus*, which is by far the most serious butt rot of conifers in Great Britain, is seldom associated with any considerable damage in North America, although it is of general occurrence there. This may be due to differences in climate, in the forest conditions (most of the reports of extensive *Fomes annosus* attack in America have come from plantations), or in the fungus itself. The possible existence of different strains of fungi in different countries is one which will be mentioned again, and which is worthy of intensified study.

It is probable that in the future, especially in the west, American forests will tend to be cut on much shorter rotations. As a basis for these changes a more intensive study of rot in second-growth and subsequent stands than has yet been carried out, is obviously called for. This study would have additional value if it could be linked up with similar studies in stands of the same age in Europe.

Conifers in North America are attacked by a number of needle diseases, which are of considerable interest to us. *Rhabdocline pseudotsugae* has so far proved far more serious in Europe than in America, where it occurs sporadically along the coast and in the interior of British Columbia. In Colorado, if present at all, it is rare, which is curious in view of the fact that the disease is so severe on the so-called Colorado Douglas fir in Europe. It is very possible, of course, that its absence is due to the dry climate of Colorado; Colorado Douglas planted in Washington State were seen quite heavily attacked. There are certainly several varieties of *Rhabdocline* in America, varying in the form of their fructification and spores, and probably also in their pathogenicity.

Another important disease of Douglas fir is *Adelopus gaumanni*. This has been found, from collections made by Wilson, Childs, and Boyce, to occur over a large area in north-west America, but it does not appear to be doing any

appreciable injury to the trees. It has also been found in eastern America on plantations, again doing little damage. In south Germany and Switzerland it is now regarded as a serious epidemic disease; in this country it has been recorded from several places, and in some does seem to be associated with damage to the trees.

Here again, the whole question of varietal resistance needs to be studied, and also the possibility of variation in the fungus. It seems hardly possible that climate alone can account for its varied behaviour in different countries. In America, Douglas fir tends to be regarded as a single species (with the exception of the quite distinct and comparatively unimportant *Pseudotsuga macrocarpa*); in Europe the general tendency has been to recognize two species, *P. glauca* (Colorado Douglas) and *P. taxifolia* (Coast Green Douglas) with one variety, *P. taxifolia caesia* (Intermediate or Interior Douglas). Probably neither concept is wholly right. Examination of trees in the field in ten states and in British Columbia, and examination and measurements of collected material, strongly suggest that no clear division into species can be made, and that all the characters tend to vary over a wide range. Nevertheless, the variation is such that to regard the Douglas fir as a single botanical entity is quite unreasonable. The work of Munger and Morris (28) on Douglas fir collected from only a very small part of its range shows this clearly. It is certainly a genus in which selection of desirable types would prove valuable from both silvicultural and pathological points of view. Such selection could be carried out on individual trees or on special small areas. Quite certainly the tree varies so much that one cannot collect seed in any one state or even in any one forest and expect to get a uniform type in growth or resistance to disease.

Other needle diseases of interest are *Hypodermella laricis* and *Rosellinia herpotrichoides*. The former is common on larch in British Columbia and Idaho, where the browning of the needles is very striking. It is not considered a serious disease in America, but might prove an undesirable alien if brought to Europe. The latter occurs only in damp valleys in the Southern Appalachian Mountains on Tsuga (19). It is not in any way a serious disease, but it should not lightly be allowed to spread to *Tsuga* stands in other situations with a damp climate, either in western America or in Europe.

Perhaps the most striking tree disease in America in the summer of 1938 was *Gnomonia veneta* on planes (*Platanus* spp.). It was very general and in places extremely conspicuous. This was particularly so in some of the river valleys near the Californian coast, where in mid-May there was hardly a live leaf left on most of the trees. It was apparently a year when the attack was particularly severe. If such attacks occurred frequently, they would certainly cripple the trees. The fungus occurs in this country, but never with such amazing virulence. In the New England states the willows were suffering very serious defoliation and dieback owing to attacks by *Physalospora miyabeana* and *Fusicladium saliciperdum*, and many trees had been killed. These fungi are also present in Great Britain, where their attack is sometimes very severe, though the damage that they do is certainly never as extensive as in New England.

Possibly the most striking difference between the fungi attacking trees in America and in this country lies in the very large number of canker-forming fungi which occur in America. In Great Britain, the pathogens known to be associated with canker could probably be counted on the fingers, and with the exception of bacterial canker of poplars, *Nectria* on beech and fruit trees, and *Dasyscypha*—whose role is not yet fully understood—on larch, none are known to be really important. To these must be added frost, also a common cause of canker in conifers in this country. But both in number and in extent of injuries the American situation is very much more serious. Admittedly many of the American pathogens, such as *Phomopsis lokoyae* (4) on Douglas fir, the fungus causing canker on Douglas fir at Sedalia (32), *Aleurodiscus amorphus* (14) on *Abies*, *Cephalosporium* sp. (7) on *Abies*, *Cytospora* sp. on spruce and on poplar (24, 33), *Tympanis* sp. (15, 24) on pine, and *Caliciopsis pinea* (31) on pine, are all largely controlled by the condition of the trees on which they are found, and do not occur on unsuppressed trees growing under really satisfactory conditions. It must be remembered, however, that trees often occur outside their optimum range, either naturally or by planting, and in these situations fungi such as those mentioned above may be very serious. In view of the frequency with which we in this country plant trees on sites unsuited to them, it is surprising that we have had so little trouble with such fungi. Possibly trouble is yet to come when more of our post-war plantations reach the pole stage.

In addition to the above, America has many other serious canker-forming fungi. Among the rusts *Cronartium ribicola*, recent accounts of which will be found in a number of papers (6, 18, 24, 25, 26), stands supreme, but there are others which are quite serious. *Endothia parasitica* (Chestnut Blight) (12) is well on its way to eradicating American chestnut from that continent. Breeding work, using resistant Asiatic *Castanea* species, has now been undertaken (8) as the only real hope of re-establishing the chestnut in America. This disease is certainly the outstanding example of a devastating fungal epidemic in trees. So thorough has the work of the fungus been that it was only in the Southern Appalachians that the author could be shown chestnuts still alive, though, of course, attacked. This disease should bring home to us not only the enormous importance of diseases in the forest, but also the fact that there are diseases which are not controlled to any extent by their environment, and which can only be avoided by quarantine or breeding for resistance. Desirable as is the present tendency to stress the importance of good environment in the health of the tree, it should equally be realized that there are fungi such as *Endothia* and *Ceratostomella ulmi* (Elm Disease) which are truly diseases in their own right.

Almost as striking as Chestnut Blight and Blister Rust are the *Nectria* cankers (18, 24, 36, 37, 41) on the hardwoods of the East. Nearly all the important species are attacked, and it is almost impossible to walk any distance in an eastern forest without seeing a typical *Nectria* canker. In Great Britain, we have a *Nectria* on beech causing the same death of patches of bark and cambium and forming poorly developed cankers, similar to those on beech in Maine

and eastern Canada; but in this country the disease is definitely associated with certain types of unsuitable site, whereas in America it is said to be both widespread and serious (11). In addition to *Nectria*, *Strumella coryneoidea* (2, 18, 24) causes a serious canker on oak, and *Eutypella parasitica* (9, 24) on maples.

As in Europe, the question of canker on poplars is rather confused. *Cytospora* cankers on poplar (33) have already been mentioned. *Dothichiza populea* is considered to be of widespread occurrence as a cause of canker in this genus. *Hypoxylon pruinatum* (18, 24, 30) is common as a cause of canker on aspen poplars, and in Colorado and Utah aspen is subject to very striking black canker (27), the cause of which is unknown. Recently a canker of poplar caused by *Septoria muciva* has been investigated by Beir: it occurs in Canada and in northern New York State, and will probably be found to occur more widely on further investigation. Of the types of poplar canker seen in America, this most closely resembled the bacterial canker (*Pseudomonas rimaefaciens*) which is so severe on certain varieties in this country and in northern Europe, but it was easily distinguishable in its earliest stages and has an entirely different host range. *Septoria* canker attacks particularly poplars of the *Populus berolinensis* group, but does not appear to affect *P. eugenii*, *P. candicans*, and *P. trichocarpa*, the three chief victims of bacterial canker in this country. In addition to these known causes of poplar canker, a vast amount of canker and dieback, much of which cannot be attributed to any of the pathogens already mentioned, is to be seen in America. Some of this is certainly due to drought, some to unsuitable soil. The whole problem is certainly worth investigating, for in many of the drier areas of the States poplars are the chief trees giving shade, and some poplars, particularly aspen and *P. trichocarpa*, have a considerable forest value.

Mistletoes are very common on hardwoods and conifers in America, causing distortion, canker, and dieback. Damage from the dwarf mistletoes, which attack conifers in the West, is often very serious, and these parasites certainly form a major pathological problem. It is not known whether they would find suitable climatic conditions for their development in Europe, but their introduction should certainly be avoided. Other cankers of importance not already mentioned are those caused by *Atropellis* sp. on pine (24) and by *Coryneum cardinale* on cypress. Both appear to be capable of attacking quite healthy trees. The *Coryneum* canker, which occurs mainly on *Cupressus macrocarpa*, appears to be spreading in the west, which is so far the only area in which it is known to occur.

In contrast to cankers, root diseases in the forest appear to have attracted less attention than in Europe. *Armillaria mellea*, though of very general occurrence and certainly sometimes associated with injury to forest trees, has received most attention owing to its activities in orchards (39). Recently *Polyporus schweinitzii* has been found attacking the roots of young pines, behaving in the same way as *Armillaria mellea* and *Fomes annosus* in this country. It has been found capable of infecting the roots of healthy young pines (40), although the full development of the disease is certainly to some extent dependent on site factors. *P. schweinitzii* is known to produce different strains, varying in their

capability to decay wood. Very possibly they vary also in their power to attack roots. It is to be hoped, at any rate, that *P. schweinitzii*, which in this country has only been found so far as a rot of middle-aged and old trees, will not prove capable of attacking young trees here.

Another root fungus, *Ozonium omnivorum*, is of interest. This soil-inhabiting fungus is capable of attacking a very wide range of plants, including many trees. It occurs in part of the southern end of the area comprised in the shelterbelt scheme, and many of the trees used for shelterbelt planting are susceptible. To avoid losses a survey was made (29), using susceptible crop plants and weeds as indicators of the presence of the fungus. In the areas known, as a result of this survey, to be infected, shelterbelts will not be planted or resistant species will be used. Surveys of this nature might have considerable application in the case of other tree diseases.

Elm disease, which certainly ranks as the most serious disease of ornamental trees in America, is too vast a subject to discuss here. Suffice it to say that, despite untiring efforts at eradication, there is still a very grave risk of the disease getting out of hand. It may well be that the future of the elm in America will depend, as it does in this country, on the possible existence of resistant trees in the natural stand, and on the breeding and selection of resistant varieties.

Two particularly interesting diseases were seen. The first, Brooming Disease of *Robinia* (22), is caused by a virus. This is one of the few known examples of virus diseases of forest trees. It seems likely that more intensive investigation will lead to the discovery of others. The second disease is a curious forking of pine associated with the presence of the fungus *Dematium pullulans* (23). After growth has ceased in the summer, and winter buds have been formed, one or more of the side buds resumes growth. Rivalry between these shoots and the leading shoot in the next season leads not, as might be expected, to permanent forking, but to very bad joints between the eventual winner and losers of the rivals. These bad joints are a frequent source of entry for decay and canker fungi, and may be rendered even worse since they are particularly liable to snowbreak. Evidence suggests that the fungus may be the cause of the stimulation of the side buds. Forking in conifers and hardwoods is very common in our plantations, and some causes—such as frost, bird, and insect damage—are already known, but injury of the type described here may well be of more general occurrence, and is worth watching for.

Space does not permit of more than a brief mention of the many physiological diseases of trees occurring in America. Frost damage occurs quite frequently both in the form of winter injury, and from early and late frosts, but, in proportion to the forest area of the country, frost damage is certainly not as serious a source of loss as in Great Britain. Drought, on the other hand, is much more serious in America, as would be expected in a country with desert regions. Deficiency diseases are also of very common occurrence. In the prairie region, for instance, lime-induced chlorosis is very marked and seriously limits the varieties of trees and shrubs that can be planted.

As already stated, forest pathology in America is a young science not overburdened with tradition. Therefore it is easily adapting itself to the modern concept that forest pathology is not an isolated science, but one inextricably linked to many related sciences, such as ecology, soil science, and plant physiology, to quote only a few. One aspect of forest improvement now attracting increasing attention in America is tree breeding and the selection of desirable types. This work will not be discussed in detail here, as it is fully described by Schreiner (34). In this development the disease resistance of the tree is receiving attention as well as its desirability from other points of view.

The consideration of diseases in another country leads one inevitably to the vexed and difficult subject of quarantine legislation. One very stringent example of this was met at the borders of California. It seemed harder to take plants or botanical specimens into California from the rest of the States than into the United States from abroad. This quarantine, designed to protect the fruit industry, a mainstay of Californian economy, has been fully described and its effects analysed (35). California, bounded by mountain, desert, or sea on all sides but the north, is naturally an area fairly easily protected. Only under such comparatively ideal conditions can a land quarantine barrier hope to be even partially successful. It is clearly easier to conduct a quarantine when the barrier is mostly sea, as in the case of the United States and Canada regarded as a unit. But the increasing speed and ease of travel, the general undesirability of restrictive measures, and the impossibility of detecting all diseases present by rapid inspection of packed plants, all militate against the eventual success of measures such as those now in force to prevent the spread of plant diseases. This whole question has been covered by Güssow (13). One's first reaction after a tour such as that made by the author is to feel impressed by the number of possibly dangerous tree diseases which exist in America and not in Great Britain and vice versa, and to think that more and stricter quarantine rules should be enforced. Only a consideration of the difficulties of such rules and restrictions and of the fact that to be effective they must continue as long as the susceptible crop is grown in the one country and the disease exists in another, can modify this impression.

On further thought, the author feels that the future will be concerned rather with ensuring by periodic inspection and licence, as advocated by Güssow, that the nurseries where export stocks are grown, are healthy, and above all with the selection and breeding of resistant strains. Admittedly tree breeding and selection is a long business, though not so long as some would suppose. We cannot afford to neglect it on those grounds, yet it is sufficiently arduous to make it necessary that it shall be conducted on an international basis. If one country raises trees resistant to a certain disease, they should be given freely to other countries interested. In the case of a tree like the poplar, which suffers from a number of serious diseases that vary markedly in their effect on different varieties, it is highly desirable that every new hybrid or selection of good growth should be tested for resistance to all the most damaging diseases. Then, if at some future date these diseases achieve a world-wide distribution, there would

be full information on the resistance of the existing trees. With poplars, tests for resistance to *Septoria* canker, *Dothichiza* canker, and possibly *Hypoxylon* canker, as well as to American *Melampsora* rusts, could be carried out in America, and tests for bacterial canker, possibly *Nectria* canker, and European *Melampsora* rusts, which have a different host range from the American ones, in Europe. Arrangements such as this could only be achieved by close international co-operation.

In the first place, it is probably desirable that such schemes should arise spontaneously by co-operation between research workers rather than that they should be imposed from above, even though they may in consequence be limited and incomplete.

Perhaps the happiest memory of the author's tour was the complete freedom with which information and offers of such co-operation were given. Ideally such co-operation should be stimulated by visits and by the exchange of research workers, so that each country may be really closely in touch with the problems of the other. At the moment, the world economic situation and the consequent lack of money for research purposes make such exchanges or visits very difficult to arrange; nevertheless, they should be continually and unceasingly encouraged. For only by such means can that co-operation be established which is so vital for the healthy continuance of an international science.

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ROOT-ROT OF SWEET CHESTNUT AND BEECH CAUSED BY SPECIES OF PHYTOPHTHORA

II. INOCULATION EXPERIMENTS AND METHODS OF CONTROL[1]

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INOCULATION EXPERIMENTS.

Resistant and susceptible species. It has been abundantly proved, both by field observations and inoculation experiments that *Phytophthora cambivora* (Petri) Buis. and *Ph. cinnamoni* Rand are the cause of root disease of *Castanea* species and many of their other hosts. The general conclusion arrived at by experiment and observation is that *C. sativa* Mill., the European Sweet chestnut, is highly susceptible to infection, *C. crenata* Sieb. et Zucc. (= *C. japonica* Blume), the Japanese chestnut, is resistant, the other eastern Asiatic species such as *C. mollissima* Blume, *C. henryi* Rhed. and Wils., *C. seguini* Dode, are also resistant, and that *C. dentata* Barkh., the chestnut of eastern North America, is susceptible. There seems to have been little or no attempt in Europe to determine whether resistant strains occur within the native species. Dugelay (14), however, refers to chestnut grafted on a disease resistant stock, namely *Castanea sylvestris microcarpa*. Petri (24) also inoculated wild trees (of German forest origin) from a region free from disease and Italian cultivated trees, using three of each sort. The wild trees were the more resistant, one surviving inoculation, and he came to the conclusion that they belonged to a somewhat resistant strain. This conclusion is, however, based on too few trials as the results recorded below indicate. No attempt has been made in this work to discover any such resistant strain or individuals among the chestnut in this country. It would not appear probable, however, that these, in so far as they may exist, have seriously affected the incidence of disease. Dufrénoy (7), however, remarks that it is usual to find trees remaining apparently healthy and unaffected in the midst of diseased areas, and it would seem possible that some of these may have higher powers of resistance than the average.

The difference in resistance between the susceptible and the resistant species has been demonstrated both by inoculation and by experience in the field (25, 11, 13, 18). The resistance of the various varieties of Japanese chestnut seems to come out plainly. Their marked success in France, in regions in which the native chestnut has been disastrously affected by disease, seems to show beyond question that (under the conditions which exist there) they are so resistant to infection that losses from disease will be negligible (29, 11, 13, 4).

[1] Part I appeared in *Forestry*, xii (2), pp. 101–16.

Crandall (5), however, claims that in Louisiana *C. crenata* and also the resistant *C. mollissima* may succumb to infection. This suggests that conditions may occur where these species are not resistant, or that strains of parasite exist to which they are susceptible. The resistant powers of the Asiatic Sweet chestnuts, and especially of *C. crenata*, has caused them to be the main hope of reconstituting affected native chestnut orchards in Europe, while much work is being done on them in U.S.A. in the hope of obtaining a tree suitable to replace *C. dentata*, the native North American species, which is susceptible both to *Phytophthora* root-rot and to *Endothia parasitica*, the cause of Chestnut blight. *C. crenata* is not suited to all climates within the temperate zone. Thus disappointment has been expressed in Italy (26) owing to its susceptibility to cold. Experience in England has been similar, nursery plants being severely cut back by frost both in Kent and Hampshire. *C. mollissima* is similarly affected. A recent report from U.S.A. (2) suggests that difficulties may arise owing to its susceptibility to various fungal diseases. The situation at present seems thus to be that *C. crenata* is of proved value in certain countries, such as France, but that the range of its successful utilization may be limited to a narrower region than that at present covered by the various susceptible species. In Europe, the work on this species has been concerned mainly with replacing chestnuts grown for fruits. This is the purpose for which it is probably mainly suited although, as a forest tree on suitable soil, it may reach a large diameter, if rather limited in height.

Phytophthora root-rot of beech has not been sufficiently important for any work to be done on the discovery or development of resistant strains or species.

Purpose of inoculations. The inoculation experiments made in connexion with this work were carried out to test the susceptibility of the European species of Sweet chestnut to the strains of *Phytophthora* isolated in this country; to check the susceptibility of beech, and to try the resistance of oak, which not uncommonly is to be found in an unhealthy condition in localities in which chestnut is infected with *Phytophthora* root-rot. Japanese chestnut were also obtained in order to study their resistance, both by inoculation in the laboratory and by planting in the field in affected areas. A few elms and some *Nothofagus* were also inoculated.

Origin of experimental trees. The European Sweet chestnut seed was obtained from trees growing in Bagley Wood, Oxford. The oak and beech plants were obtained from Forestry Commission nurseries. A donation of Japanese chestnuts was most kindly sent to the laboratory by M. Jean Dufrénoy. Further supplies of this species were raised from seed of the variety Shiba Guri obtained from Messrs. Vilmorin et Fils of Paris. Later, a donation of seed of both *C. crenata* and *C. mollissima* was generously sent by the U.S. Dept. of Agriculture through the kind offices of Professor R. Kent Beattie. The work on the trees raised from this seed is still in progress. It is, also, still too early to report on any trees of supposedly resistant species planted out in the field.

Inoculations, 1932–5. The inoculation was made in March and April by inserting mycelium of the fungus into a small cut made just above soil level in

the bark of the main stem of the tree. Trees 2 to 4 years old were used. They were grown in pots for convenience in moving for inoculation and examination. The pots were buried in soil up to their rims. The plants were watered when necessary, but were not kept especially moist. The soil in which the pots were

TABLE I

Date of inoculations.	*Host.*	*Parasite.*	*Origin of parasite.*	*Number of trees.*		
				Killed.	*Partly girdled.*	*Healthy.*
1932	*Castanea sativa*	*Phytophthora cambivora*	*C. sativa*	6	5	1
"	"	"	*Fagus sylvatica*	4	7	0
1933	"	"	*C. sativa*	12	23	5
"	"	"	*F. sylvatica*	7	12	2
1934	"	"	"	16	21	3
			Total	45	68	11
"	"	*Ph. syringae*	*F. sylvatica*	6	2	0
"	"	*Ph. cinnamomi*	*C. sativa*	5	11	4
1932	*Fagus sylvatica*	*Ph. cambivora*	*F. sylvatica*	1	5	0
"	"	"	*C. sativa*	2	4	0
1933	"	"	*F. sylvatica*	0	15	5
1934	"	"	"	23	8	11
			Total	26	32	16
"	"	*Ph. syringae*	*F. sylvatica*	9	0	3
"	"	*Ph. cinnamomi*	*C. sativa*	0	6	20
1932	*Ulmus* spp.	*Ph. cambivora*	*C. sativa*	0	1*	0
"	"	"	*F. sylvatica*	0	1*	0
1933	*Quercus* (*robur* × *sessiliflora*)	"	"	0	8†	2
"	"	"	*C. sativa*	0	7†	3
1934	*Nothofagus* spp.	"	*F. sylvatica*	2	4	6
1934	*Castanea crenata*	*Ph. cambivora*	*F. sylvatica*	8	0	0
1935	"	"	"	80	0	0
"	"	"	*C. sativa*	36	0	0
"	"	*Ph. syringae*	*F. sylvatica*	22	0	2
"	"	*Ph. cinnamomi*	*C. sativa*	15	0	9

* Only $\frac{1}{8}$ inch of bark remained alive. † Only slightly affected.

buried is a well-drained gravel. The results of the inoculation experiments are given in Table I.

These show that, under the conditions of the experiment, both *C. sativa* and *F. sylvatica* are susceptible through wounds to infection by *Phytophthora cambivora*, whether the parasite was originally obtained from beech or from chestnut. *C. sativa* is also susceptible to both *Ph. syringae* and *Ph. cinnamomi*, while

F. sylvatica appears equally susceptible to *Ph. syringae* but much more resistant than *C. sativa* to *Ph. cinnamomi*. General observation in the field suggests that *F. sylvatica* may be more resistant to both *Ph. cambivora* and *Ph. cinnamomi* than is *C. sativa*, and the inoculations confirm this, on the whole. However, it is difficult or impossible to make adequate comparisons under field conditions, since the two species of tree are not commonly planted together. The observed resistance of beech may be due, at least in part, to its absence from some of the heavier or compact moist soils on which chestnut has often been planted. This can only be tested by further observation. In this connexion it is interesting to note that all the fifteen oak successfully inoculated were only slightly affected. Oak would thus appear to have high powers of resistance to infection by *Ph. cambivora*, which enhances its suitability as a tree for heavy soils. The *Ulmus* and *Nothofagus* species used both proved undoubtedly susceptible to infection by *Ph. cambivora*, and the known host range of all three species of parasite suggests that many other species of tree would similarly be so.

Infection experiments on *Castanea crenata* produced results which were quite contrary to what were expected. The plants sent by M. Dufrénoy were received in 1933. They were allowed 12 months in which to become established and to recover from moving. Eight were then inoculated in 1934, as shown in Table I, and all of them died. The parasite was re-isolated from the infected plants. The control plants remained healthy. This result proved to be so unexpected that a large number of trees raised from seed of *C. crenata* obtained from Messrs. Vilmorin et Fils, of Paris, were inoculated in 1935, with the result shown in the table. All those infected with *Ph. cambivora* died; *Ph. syringae* proved to be nearly as virulent, while *Ph. cinnamomi* was rather less so.

Inoculations 1936–7. In 1936 and 1937 three methods of inoculation were used. On some trees the bark was slit to the wood and mycelium inserted; on others the cork was scraped off the stem and mycelium placed against the exposed tissues, while in yet others mycelium was mixed with the soil. With half of the latter the soil was covered with moss; in the other half it was left bare. It was felt that perhaps the small size of tree might be responsible for the high death-rate, and in 1937 half the trees used were a year older than those inoculated in the previous year and considerably larger. All seemed to be healthy, reasonably vigorous plants. The results of the inoculations are given in Table II.

They show fairly clearly that under the conditions of the experiment *C. crenata* is susceptible to infection by *Ph. cambivora* to a high degree; that it is rather less susceptible to infection by *Ph. syringae*, and that it shows still more signs of resistance to *Ph. cinnamomi*. The different methods of inoculation show that successful infection can be obtained even if only the cork is removed. The failure to obtain any clearly successful infection with mycelium mixed with the soil may easily be due to the difficulty of obtaining a really strong growth of the parasite under these conditions, because experiments with germinating nuts of *C. sativa* showed that the white root-tip was easily penetrated by *Ph. cambivora* when mycelium was merely laid across it. The inoculation of

trees of different size showed also that the larger ones were less susceptible than the smaller. This had been observed previously with *C. sativa*.

Spring and summer inoculations. A certain number of trials were also carried out to see if there might be any indication of greater or less susceptibility to infection if trees were inoculated in the spring (April) or in the summer (July).

TABLE II. *Inoculations of* Castanea crenata, (A) *with* Phytophthora cambivora *ex* Fagus sylvatica, (B) *with* Ph. syringae *ex.* F. sylvatica, (C) *with* Ph. cinnamomi *ex* C. sativa.

Reference letter.	*Year.*	*Type of inoculation.*	*Size of tree.*	*Number of Trees*	
				Killed.	*Healthy.*
A.	1936	Bark slit	..	14	1
	1937	„ „	larger	3	3
	„	„ „	smaller	6	0
	1936	Bark scraped	..	15	0
	1937	„ „	larger	2	4
	„	„ „	smaller	6	0
	1936/7	Inoculum mixed with soil*	..	3†	41
B.	1936	Bark slit	..	2	3
	1937	„ „	larger	3	3
	„	„ „	smaller	6	0
	1936	Bark scraped	..	..	5
	1937	„ „	larger	2	4
	„	„ „	smaller	3	3
	1936/7	Inoculum mixed with soil*	..	0	24
C.	1936	Bark slit	..	2	10
	1937	„ „	larger	2	4
	„	„ „	smaller	3	3
	1936	Bark scraped	..	3	3
	1937	„ „	larger	..	6
	„	„ „	smaller	3	3
	1936/7	Inoculum mixed with soil*	..	..	44

* Soil under half of plants covered with moss.

† Moss-covered soil; plants died in typical manner, but parasite not re-isolated.

The results of these are shown in Table III. They indicate that *Ph. cambivora* is probably more virulent, both towards *C. sativa* and *F. sylvatica*, in April than in July, and that, on the contrary, *Ph. cinnamomi* is probably more virulent in July than in April. There is also some indication that strain (B) of *Ph. cambivora* is more virulent in April than either (A) or (C).

Inoculation of trees from U.S.A. seed. The inoculation experiments on the *C. crenata* raised from seed received from the U.S. Dept. Agric. are reported separately in Table IV. These were made in 1937. The trees were divided into two lots. One lot was planted in garden soil which is derived from river gravel containing a mixture of limestone pebbles of Jurassic origin from the Cotswold Hills, and Bunter pebbles of Trias origin. The other lot was planted in an acid

sandy loam of fluvio-glacial origin obtained from Bagley Wood, near Oxford. *Calluna vulgaris* occurs sporadically on this soil. The object of this was to test whether there was any difference in susceptibility between trees growing in the different soils. Also it has been reported that *C. crenata* is markedly calcifuge (29). It has, however, always grown well on the garden soil as a small tree.

TABLE III

Month of inoculation.	*Parasite.*	*Origin of Parasite.*	*Host.*	*Number of trees.*		
				Killed.	*Partly girdled.*	*Healthy.*
April	*Phytophthora cambivora*	*Fagus sylvatica* (A)*	*Castanea sativa*	0	5	1
,,	,,	,, (B)	,,	6	4	0
July	,,	,, (A)	,,	0	5	1
,,	,,	,, (B)	,,	0	6	0
April	*Ph. cinnamomi*	*C. sativa*	,,	0	6	4
July	,,	,,	,,	5	5	0
April	*Ph. cambivora*	*F. sylvatica* (A)	*F. sylvatica*	6	2	4
,,	,,	,, (B)	,,	10	2	0
,,	,,	,, (C)	,,	7	4	7
July	,,	,, (A)	,,	0	3	3
,,	,,	,, (B)	,,	0	0	6
,,	,,	,, (C)	,,	0	2	4
April	*Ph. cinnamomi*	*C. sativa*	,,	0	1	11
July	,,	,,	,,	0	5	9

* The letters denote strains of *Ph. cambivora* isolated from trees in different places.

TABLE IV. *Inoculations of* Castanea crenata (*U.S.A. origin*), *May 1938. Trees grown in* (A) *acid sandy loam*, (B) *in gravel soil containing limestone pebbles.*

Reference letter.	*Parasite.*	*Origin of parasite.*	*Number of trees.*		
			Killed.	*Healthy.*	*Died of other causes.*
A.	*Ph. cambivora*	*F. sylvatica*	5	1	2
B.	,,	,,	0	4	4
A.	*Ph. syringae*	,,	6	1	1
B.	,,	,,	1	3	2
A.	*Ph. cinnamomi*	*C. sativa*	5	1	2
B.	,,	,,	1	6	1

The results of this experiment were complicated by the dying of 12 out of the 46 trees inoculated, and 4 out of the 12 controls from a cause other than the parasite. This is believed to have been frost; trees raised in Bedgebury nursery from the same seed also suffered badly from frost. The trees are of a large fruited variety of *C. crenata* and therefore probably of a different strain from those used for the previous experiments. These inoculations are of interest

because they indicate that the trees in the acid sandy loam were more susceptible to infection than those in the garden gravel. The parasite was re-isolated from half of those which were girdled in the typical manner around the point of inoculation. The experiment perhaps further indicated that these *C. crenata* were less susceptible to root-rot when growing on garden soil than the trees previously used and raised from French seed. The necessity of reserving plants for field trials prevented the repetition of this work.

Inoculation of large beech. Apart from the above laboratory experiments, six vigorously growing beech of about 30 feet in height were inoculated, two trees being used for each species of parasite. Half the trees had the bark slit, the other half having the cork only removed. The inoculation succeeded only in the two trees inoculated with *Ph. cambivora*. The infection took well in both but spread fastest in the tree the bark of which was slit. The parasite was re-isolated.

The above experiments seem to show beyond doubt that under certain conditions, at least, *C. crenata* is susceptible to infection by *Phytophthora* species causing root-rot, and that there is some variation in its resistance towards various species of parasite. This chestnut is, admittedly, on the edge of its possible climatic range in Britain and it is quite possible that this may affect its powers of resistance to infection. On the other hand, field trials may eventually show that this species is much less susceptible than laboratory experiments indicate. It must be some time before these can be reported on, should the trees escape the dangers of early and late frost.

CONTROL OF THE DISEASE.

The principal methods of control of the disease among Sweet chestnut in Europe have been the destruction of the parasite in the soil, or in the bark of the tree, and the replacement of the susceptible native tree by the resistant Japanese species. To some extent manures have been used to stimulate the growth of infected trees and help them to recover from infection. Often several methods of control have been applied at the same time.

Soil sterilization. There are numerous references to this method, but it is probably of practical use only in the treatment of valuable specimen trees. Blin (3) suggested watering planting-holes with a 20 per cent. solution of sulphate of iron, which is one of the soil disinfectants most commonly used. Dufrénoy (7) recommended in an early stage of the disease that a solution of 3 kilograms of this salt dissolved in 10 litres of (hot) water be applied immediately round the base of the tree, and also that in the autumn or winter a dressing of 1 kilogram to every square yard might be applied over the roots. Copper and calcium sulphates have also been recommended (19). Bordeaux mixture has been used to treat both the bark and the soil. A 2 to 5 per cent. solution has been recommended, 1·5 per cent. of glue being added to give it adhesive properties. It may be sprayed on the roots to prevent infection (20), or it may be used to treat the soil (21, 9). Watering the soil with a strong solution of potassium permanganate is said to have given good results (7). Calcium cyana-

mide has been recommended by Petri (22): this is also a nitrogenous manure. The rate of application should be 1 to 2 kilograms to each full-grown tree, the substance being spread round the base of the tree for a distance of 3 to 4 metres. Carbon bisulphide and calcium sulphide have been recommended as not only keeping the fungus in check, but also killing grubs which may cause wounds through which infection enters (7).

Destruction of infected tissues. If a tree is only slightly affected it may be saved by destroying the parasite in the infected tissues. This is possible in an early stage of the disease, because infection takes place near to the soil surface, and the infected tissues occur not far above or below this. A small trench is dug round the base of the tree, and the diseased bark is exposed and left clean of soil. According to Petri (23) and Landaluze (17), the growth of the parasite is retarded by winter cold and on exposure of the bark it dies out, possibly owing to the competition of fungi less affected in their growth by low temperature. Rate of growth experiments carried out by the author have indicated that, of the three species of *Phytophthora* here discussed, *Ph. cinnamomi* is the most retarded in rate of growth by low temperature, although as freezing-point is approached all grow very slowly or not at all. Another factor in exposure may be the drying out of the affected bark. Gioda (16) recommends that in severe cases the older branches are cut back in addition to having the bark exposed, and states that trees so treated have always recovered well.

As an alternative to mere exposure the diseased bark may be cut away (10, 17), and the treated area disinfected with one of the substances mentioned above. Copper carbonate is stated also to be of good service in this way (17). A fixative such as calcium caseinate must be used to cause it to adhere. The soil round the tree may also be disinfected at the same time. The author treated several chestnut and beech in an early stage of disease by excising the diseased tissues, the wound being coated with Stockholm tar and left exposed to the air. The soil was not disinfected. All the trees recovered satisfactorily.

There is an obvious danger that the trees may be re-infected when treatment is confined to the exposure or excision of diseased tissues. Neither local disinfection nor the application of fertilizers is likely to prevent this.

Cultural measures. Some short mention must be made of these, although none, except the introduction of resistant types, have been effective in combating the disease.

In Italy, chestnut leaves are gathered into heaps to form compost: it has been found that *Ph. cambivora* lives in such heaps and spreads from them, and it has accordingly been recommended that all leaves be burned (20). It has also been recommended, in Italy, that high forest be converted into coppice because of the relative immunity of the latter to disease (15, 21). It will have been seen in the first part of this paper (6) that this is not the experience in Britain. Prunet (27) also notes the susceptibility of coppice to this disease.

Rands (28) states that the control of stripe disease of cinnamon, which is caused by *Ph. cinnamomi*, can be effected to some extent by the prevention of the wounding of the root and the maintenance of good drainage. These

conditions are most nearly realized in so-called 'forest cultivation' in which cinnamon is planted closely on steep slopes. Cultivation or grazing may be carried out between trees in other situations with the result that wounding of the roots frequently occurs. There is a certain amount of evidence with regard to chestnuts pointing in the same direction. Thus Roy (30) pointed out that wild trees scattered through the forest on the mountain side, in Corsica, were free from disease, whereas the cultivated trees at lower altitudes were succumbing and were being replaced by the resistant Japanese species. There is no evidence that forest conditions necessarily reduce susceptibility to disease in England; conditions relating to soil moisture and drainage are of much greater importance (6).

The use of artificial fertilizers has been recommended and found effective in ameliorating the condition of diseased trees (5, 7, 8, 17, 23, 31). Such treatment is of value in connexion with other means of control; it will not usually be of great value by itself.

Resistant species. Evidence submitted above shows that under certain conditions *Castanea crenata* is susceptible to infection by *Phytophthora* species, but the general evidence of the literature, mainly consisting of reports from France and Italy, is that this species, and also the various Chinese species of Sweet chestnut, are highly resistant to *Phytophthora* root-rot (4, 11, 13, 18, 25, 29). *C. crenata* is the only species which has been widely used in Europe to replant orchards of the native species infected with root-rot. It has been stated to remain free from disease even under unsuitable soil conditions (a hard dry compact clay) when native trees similarly planted died within a year or two (27). It is doubtful whether this species has any real value in high forest, for, apparently, it only grows to a moderate height; it may, however, be useful as coppice (29). Renoux (29) states that the Basque country in the south-west of France has a climate which, on the whole, is favourable to this species. It is mild, very humid, and has very warm summers. It is found there to be somewhat sensitive to sun-scorch, to be liable to suffer from early frost, and also to suffer from strong winds. In Japan it prefers a mild climate with humid air and a moist soil. A deep clayey sand is stated to provide the type of soil which suits it best. It grows well on soils which drain quickly, but refuses to do well on those which are too compact. It is said to be absolutely calcifuge. It grows faster than *C. sativa* at first, but more slowly after about 15 years. These remarks apply to the variety Tamba Guri, which is universally employed in this part of France. The variety Shiba Guri, which has been used for the inoculation experiments described in this paper in so far as the trees have been raised from French seed, comes from mountainous regions and it is considered that it might be suitable for a ruder climate than that of the Pays Basque. Dufrénoy (12) gives similar information with regard to this species.

If the above description of the character and requirements of *C. crenata* may be taken as generally true, it seems unlikely that the tree will be of much use on the rather compact water-retentive soils on which *Phytophthora* root-rot is most virulent in England (6), while trouble from frosts is only too likely,

except perhaps in mild coastal regions, and, indeed, has already occurred. Bean, however, states that trees established at Kew are doing well (1). He also states that *C. Henryi* and *C. mollissima*, both of which are resistant species, have been established there and have proved hardy, but are slow and bushy in growth. Kew has a fairly mild climate. The *C. mollissima* raised in the nursery at Bedgebury, Kent, have been rather severely injured by frost, and *C. Henryi* has proved susceptible to frost injury in Hampshire. The slow growth of these species seems to indicate that they will be of no use as timber trees in this country, even if they should prove to be sufficiently hardy.

The control of *Phytophthora* root-rot in this country at present depends mainly on the avoidance of soil types which favour the development of the disease. These are the heavy water-retentive soils, or soils which for other reasons drain slowly or badly, and so are commonly in a wet condition for considerable periods. Where a badly drained subsoil is a factor favouring the development of disease careful draining will probably help considerably to ameliorate conditions. This is true of gley soils. The free drainable water is mostly in the structure fissures of heavy gleyed subsoils (32) and, to be effective, drainage ditches must be dug deeply so that the water is drawn off from this horizon. Shallow ditches of about 9 to 12 inches depth are of little or no use for this purpose.

The excision of diseased bark, the sterilizing of the wound and of the soil may be tried to save individual trees in an early stage of infection. Whether mere exposure of the bark will prove sufficient to prevent any further spread of infection has yet to be proved in this country. Such measures as these, and also the use of manures, are not suitable for application to whole woods.

The use of resistant species has been discussed above. Further action must wait until it has been demonstrated that *C. crenata*, the most suitable of them, is suitable for growth in this climate and is also resistant to infection. There is some doubt on both these points at present.

There seems to be no reason why Sweet chestnut should not still be planted with every hope of reasonable security provided the right soil type is chosen and plants free from infection are used. The essential features of this type are a loose consistence, completely free drainage for a depth of at least 2 feet and preferably to a greater depth, and a relatively low proportion of clay and other very fine materials. Light, well-drained non-calcareous loams of at least moderate fertility are suggested.

The planting of beech on ill-drained or heavy water-retentive soils should also be avoided. It does not occur naturally in England on such soils nor has it been widely planted on them. On the other hand, the drier and better drained heavy soils, such as are commonly derived from clay with flints overlying chalk, are perfectly well suited to beech which seems to be quite free from *Phytophthora* root-rot on them. The heavy clay loams which occur over limestone are not quite so safe, as is indicated by the occurrence of infection at Profile I described in Part I of this paper (6).

DISCUSSION.

The literature on *Phytophthora* root-rot is singularly poor in any detailed descriptions of the soil conditions associated with the occurrence of infection. It is for this reason impossible to get any adequate conception of the relationship between the condition of the soil and the occurrence of infection. One merely learns that heavy, moist compact soils are those on which it is most virulent. The profile descriptions in the first part of this paper (6), however inadequate they may be from a pedological standpoint, serve to indentify certain types and conditions of soil with the presence and absence of disease. It appears from this that in England *Phytophthora* root-rot is a disease of soils which are usually, or for considerable periods, in a very moist or wet condition, and that it is absent from soils which drain freely and have a relatively low water-retentive power, even when a highly susceptible species such as *C. sativa* is grown on them. This is true even when both types of soil are closely adjacent to each other.

It further appears that free drainage, as such, is not sufficient; it is essential also that the soil shall not be water-retentive. Thus the disease may occur on a freely draining but heavy clay loam in which the soil aggregations hold a considerable amount of water, with the result that the soil remains wet for considerable periods. Thus, improvement of drainage in a heavy gley soil will reduce disease if only by improving the physical condition for root development; infection, however, will probably still persist owing to the high proportion of clay and the consequent natural water-retentiveness of the soil (32). Drainage will, therefore, be most effective in reducing infection, as contrasted with disease arising from poor physical conditions for growth, where, given opportunity for drainage, the soil is naturally of a dry type. On shallow heavy soils with a gleyed subsoil it must often be difficult or impossible to distinguish between disease arising owing to poor edaphic conditions and that due to infection. In such instances the two sources of disease may be regarded as factors in the production of a resultant diseased condition.

The other important matter arising out of this paper is the susceptibility of *C. crenata* to infection when artificially inoculated. This would seem to indicate that conditions exist naturally under which this species is susceptible. The case of beech (*Fagus sylvatica*) is somewhat similar. The inoculation experiments indicate a rather high degree of susceptibility, especially to *Ph. cambivora*, and yet the incidence of infection in the field has never been so high, nor has the disease been so devastating as is the case with *C. sativa*, the common Sweet chestnut. The inoculations indicate that the reason for this may partly lie in the fact that beech is somewhat more resistant to infection than is *C. sativa*. This is also true for *C. crenata*. Further work is needed in this connexion, as also with regard to adverse edaphic factors as causes of disease. It has already been indicated that the distribution of the species of host in relation to soil type is a factor of importance in the consideration of relative susceptibility.

It seems idle to discuss the origin of these fungi or whether they are native to

England. Their widespread distribution across the whole south of the country suggests that they are indigenous and that to some extent they have always been a cause of disease. There is a widespread and well-recognized association of *Phytophthora* species with root-rot of trees from the seedling stage upwards, and it is probable that in the future a much wider host range will be recognized in this country than is known at present.

Thanks are due to the Forestry Commission, who have subsidized and made possible this work, and to the many foresters and landowners who have given facilities and often active assistance for field investigations.

SUMMARY.

This paper is concerned with root-rot of *Castanea sativa* and *Fagus sylvatica* caused by *Phytophthora cambivora*, *Ph. syringae*, and *Ph. cinnamomi*. The host range of these fungi is indicated and the course of development and general symptoms of disease described. Each of the parasites causes a disease of exactly similar appearance.

Phytophthora root-rot is shown to be associated with moist water-retentive soils and to be especially serious when the depth of well-drained soil is shallow and the drainage in the subsoil impeded. The disease has not been found on light, easily drained loams with completely free drainage in the subsoil. Similar soils with impeded drainage at a depth of 2 feet or more have also remained free from infection although adjacent to infected soils.

Inoculation experiments indicate that *Castanea sativa*, *C. crenata*, and *Fagus sylvatica* are all susceptible to all three species of parasite. The two latter species are shown to be rather less susceptible to *Ph. cinnamomi* than is *C. sativa*, while *C. crenata* is possibly the more resistant to *Ph. syringae*. The evidence from the field is that *F. sylvatica* is less susceptible than *C. sativa*. *C. crenata* is not grown in this country but has proved to be highly resistant in France and elsewhere. Plants raised here for trial purposes have proved to be susceptible to frost injury. Their resistance in the field to root-rot is not yet known.

The various methods of controlling the disease are discussed. The use of resistant sorts of chestnut is the most important method abroad, and, if a suitable type of tree can be found, may prove to be of value here. In the meantime the cultivation of chestnut under soil conditions which favour the development of infection should be avoided and this genus confined to the drier and more freely drained non-calcareous soils.

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EFFECT OF SAP-STAIN ON THE PROPERTIES OF TIMBER[1]

II. EFFECT OF SAP-STAIN ON THE DECAY-RESISTANCE OF PINE SAPWOOD

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INTRODUCTION.

IT is popularly believed that wood affected with blue stain is more liable to dry rot than clean wood. Several investigators have carried out tests to find out if such be the case, but their results have been somewhat inconclusive and it was felt that the question merited re-investigation. Johann (4) found that timber in which the staining fungi were alive was more resistant than clean timber, but that when the staining organisms were dead no difference could be detected. He concluded that there was no significant practical difference in resistance to decay between blue-stained and sound wood. He did not, however, give any figures showing the amount of decay in the various samples, and he suggested that blue-stained fungi may render the moisture in the wood less available to the wood-destroying fungi, but this seems most unlikely. Mayer Wegelin *et al.* (5) also concluded that heavy blue staining greatly checks the development of wood-destroying fungi.

EXPERIMENTAL PROCEDURE.

Two series of experiments have been carried out. In the first series small blocks of wood which had been artificially infected with staining fungi after steam sterilization were used, and in the second series the small test blocks were cut from the sapwood of planks which had become stained as the result of natural infection. After the samples had been dried in an oven for 18 hours at 100° C. they were weighed aseptically and then exposed, usually without further sterilization, to fungus attack by being placed in culture-flasks containing the test fungus in active growth on malt agar medium. The flasks containing the test-pieces were then kept in an incubator or constant temperature room at 22° C. for various periods, at the end of which the blocks were removed from the flasks. After any superficial mycelium had been carefully removed, they were then weighed and, after oven-drying, reweighed: in this way the final oven-dry weight and the final moisture-content were determined. This final dry weight subtracted from the initial dry weight gives the loss in weight resulting from fungal attack which is a useful measure of the amount of

[1] Part I appeared in *Forestry*, xi (1), pp. 40–52.

decay which has taken place. Expressed as a percentage of the original oven-dry weight, this loss in weight is a fair basis for comparing the resistance to decay of various timbers or of timber exposed to various treatments.

Most of the figures quoted below have been analysed statistically and the significance of the results determined.

RESULTS OF EXPERIMENTS.

Series A. Samples artificially infected with Sap-stain.

Experiment 1. Sticks of freshly dried Scots pine (*Pinus silvestris*) sapwood were cross-cut into small blocks measuring $5 \times 2{\cdot}5 \times 1{\cdot}0$ cm. Alternate samples were selected into two groups so that the samples in each of the groups were closely matched. Both groups were sterilized after they had been oven-dried and weighed, by heating in an autoclave at 15 lb. gauge pressure for 30 minutes. All the samples in the first group were then infected with a suspension of the conidial spores of *Ophiostoma* (*Ceratostomella*) *coerulea*. After 3 months' exposure to the staining fungi both sets of samples (i.e. the stained samples and the sterilized ones) were then placed on glass rests in contact with cultures of the test fungi. One-half of the stained samples were sterilized before inoculation by heating in an autoclave for 20 minutes at 15 lb. gauge pressure. The following table gives the results.

Test fungus.	*Treatment.*	*No. of samples.*	*Loss in dry wt. per cent. after 8 weeks' exposure.*
Merulius lacrymans Dry-rot fungus	Sterilized controls	18	12·5
	Stained and then sterilized	20	15·0
	Stained (staining fungus alive)	12	13·4
Poria vaillantii	Sterilized controls	9	8·7
	Stained and then sterilized	10	7·5
	Stained (staining fungus alive)	9	8·4

Experiment 2. Test blocks $5 \times 2 \times 1$ cm. were cut from the same pieces of wood but not end-matched.

Test fungus.	*Treatment.*	*No. of samples.*	*Loss in dry wt. per cent. after 8 weeks' exposure.*
Merulius lacrymans	Sterilized—oven-dry	10	33·1
	Stained and sterilized (oven-dry)	10	43·8
	Stained. *C. coerulea* alive	10	41·2

The moisture-content of the samples at the end of this test was rather too high for the optimum growth of fungus.

The difference in the first test between the percentage loss in weight of the

clean and that of the stained samples is doubtfully significant and might have been due to chance variations, but taken in conjunction with the results of the second test it would appear that the stained wood was rather more readily attacked by *Merulius lacrymans* than the sound wood, especially when the staining fungus had been killed. With *P. vaillantii* there was no significant difference in the rate of decay of the stained and of the control samples.

Series B. Tests on Naturally Stained Samples.

It has been shown in a previous paper (Findlay and Pettifor (3)) that the reduction of toughness resulting from the growth of a blue-stain fungus in pine is greater when the wood is first steamed than in unsteamed wood. Chapman (1) also found that sap-staining fungi grew more vigorously and caused a greater reduction in toughness in steamed than in unsteamed wood.

Experiment 3. Scots Pine Sapwood

Test fungus.	*Duration of Test (time of exposure to fungus)*	*No. of samples tested in each group.*	*Loss in dry wt. per cent.*	
			Clean controls.	*Stained samples.*
Merulius lacrymans	6 weeks	19	10·0	12·2
	10 „	20	13·6	16·3
Poria vaillantii	6 weeks	10	6·35	6·7
	10 „	10	7·9	9·6
Coniophora cerebella	6 weeks	10	14·9	19·0
	10 „	10	17·9	21·0

Note: The samples removed after 10 weeks' exposure were initially approximately twice the size of those removed after 6 weeks.

It was, therefore, decided to compare the resistance to certain wood-destroying fungi of clean and of naturally stained sapwood, i.e. of timber which had not been steamed before exposure to the staining fungi.

Small test-pieces were prepared from pine planks which had been used in a test made to determine the effectiveness of certain anti-stain dipping treatments. Exact matching of the test-pieces was not possible in this case, but the boards had all been cut from the same trees. Clean samples were cut from boards which had been dipped for 20 seconds in a chlorophenol antiseptic before being stacked along with the untreated boards, the sapwood of which soon became heavily stained. As the small test-pieces were cut from the inside of the boards, there was no risk whatever of their having been contaminated with even a trace of the antiseptic solution which had not of course penetrated into the boards during the dipping treatment.

These results were examined statistically, and it was found that, with the exception of the small samples exposed to *P. vaillantii* for 6 weeks, they were definitely significant, i.e. that the differences found in decay resistance between the stained and the clean groups were real and not due to chance variations in the timber or in the rate of growth of the different cultures.

Experiment 4. Sapwood of Corsican Pine, Pinus nigra *var.* calabrica.

Samples measuring $5 \times 2{\cdot}5 \times 1{\cdot}5$ cm. cut from naturally stained planks were used.

Again it was found that the stained test-pieces lost slightly more weight than the clean samples during the period of test, though statistically the differences were doubtfully significant.

Test fungus.	*No. of samples.*	*Loss in dry wt. per cent. after 7 weeks' exposure.*	
		Clean controls.	*Stained samples*
Merulius lacrymans	19	12·2	12·6
Coniophora cerebella	10	10·5	14·1
Poria vaillantii	10	5·7	7·3

Experiment 5. Sapwood of Scots Pine.

Test fungus.	*No. of samples in each group.*	*Loss in dry wt. per cent. after 2 months.*	
		Clean controls.	*Sap-stained.*
Merulius lacrymans	8 small blocks	20·6	17·8
	8 large blocks	15·7	13·8
Poria vaillantii	8	8·4	9·8
Coniophora cerebella	8	21·4	20·3

In this experiment the control blocks actually lost more weight than the stained, but the number of samples tested was small and statistical analysis shows that the differences are not significant and may have been due to chance variations in the timber and in the growth of the cultures.

Experiment 6. Sapwood of Scots Pine.

Test fungus	*Time of exposure.*	*No. of samples in each group.*	*Loss in dry wt. per cent.*	
			Clean controls.	*Sap-stained.*
Merulius lacrymans	1 month	9	3·1	4·9
	2 months	10	9·1	10·8
	3 „	15	20·3	20·8
Poria vaillantii	1 month	9	2·2	2·7

Once again the stained samples lost slightly more weight than the clean unstained ones during the period of test, the difference being proportionately greater in the earlier batches than in the last group. This suggests that the staining fungus had made the wood rather more liable to attack by the wood-destroying fungus, but that once the latter had permeated the test blocks the rate of decay became similar in the stained and in the clean blocks.

DISCUSSION OF RESULTS.

From an examination of the results of all these experiments it may be concluded that there is a slight but real difference in resistance to decay between clean pine sapwood and that of sapwood stained with sap-staining fungi, the stained wood being rather more readily attacked by certain wood-destroying fungi. This difference appears to be greater when the staining fungus is dead.

Having established that stained wood is slightly less resistant than clean wood to decay, some explanation of this difference was then sought. It is known that staining fungi such as *Ophiostoma coerulea* have little or no effect on the cell-walls, and that they derive their nourishment mainly from the reserve food-materials such as starch stored in the medullary rays. It therefore seemed unlikely that the staining fungus could have altered the cell-walls in such a way as to make the material in them more readily available to the fungi which cause decay. Two possible explanations suggested themselves: firstly, that the staining fungus produces some substances which can stimulate the growth of *Merulius lacrymans*; or secondly, that it brings about some physical alteration to the wood which makes it more suitable for the growth of the decay fungus.

Extracts of the sawdust from stained wood and from clean wood were prepared by boiling the sawdust with water, filtering and then condensing the extract so that 100 ml. contained the extractives from 100 gm. of wood. The pH of these extracts was examined, and it was found that the extract from the stained wood had a pH of 4·2 and that of the clean wood 4·6. On evaporation the extract from the stained wood left 1·4 per cent., and that from the clean wood 1·7 per cent. of solid matter respectively, indicating that some of the water-soluble material in the wood had been utilized by the staining fungus.

A medium was prepared by adding 2 per cent. of agar to the extracts. Five petri-dishes containing each medium were inoculated with *Merulius lacrymans*. Somewhat more regular and more vigorous growth developed on the medium made from the extract of stained wood than on the extract from clean wood, but in a second test no growth developed on either medium. There is, therefore, little evidence that the more vigorous growth of *Merulius lacrymans* on stained wood is due to the production of soluble materials by the action on the wood of the staining fungi, unless these materials are thermolabile.

COMPARATIVE ABSORPTION OF WATER BY BLUE-STAINED AND BY CLEAN WOOD.

At one time it was considered that the presence of blue stain retarded the absorption of preservative liquids into timber, but Saling (6), who carried out a number of carefully controlled tests, showed that the penetration and absorption both of zinc chloride solution and of creosote are greater in blue-stained wood than in clean. Using the hot and cold method of impregnation, he found that the amount of absorption was roughly proportional to the degree and depth of staining. Mayer Wegelin *et al.* (5), on the other hand, found that blue stain had no effect on the rate of absorption of water. A few tests have therefore been carried out to compare the rate of absorption of water by wood

stained with blue staining fungi with that of clean wood. Small sample blocks, square in section, were immersed in water and weighed after various periods of immersion. In one set of blocks the ends were dipped into wax to prevent the end-penetration of water. The following results were obtained. The figures in the first test represent the total absorption in grammes by 10 sample blocks in each case:

Test 1.

Time of immersion.	*Total weight of water absorbed after.*		
	½ hour.	*2 hours.*	*18 hours.*
Stained wood—ends waxed . . .	7·8	13·8	28·7
Clean „ „ „ . . .	5·6	8·9	18·4
Stained wood—no wax on ends . .	15·1	19·2	27·6
Clean „ „ „ . . .	11·8	17·3	26·7

Test 2.

	Wt. of water absorbed by 10 samples (ends waxed) after 17 hours' immersion.
Stained wood . .	52·1 gm.
Clean wood . .	40·6 gm.

Test 3. Weight of water absorbed by 12 samples with ends waxed.

	Times of immersion.		
	1 hour.	*32 hours.*	*56 hours.*
Stained . . .	54·8	84·7	93·9 gm.
Clean . . .	37·0	67·7	77·2 gm.

From these tests it seems clear that blue-stained sapwood absorbs liquid water more readily than clean sapwood, thus confirming Saling's findings, although its hygroscopicity and ability to absorb moisture in vapour form from a humid atmosphere are probably the same as that of clean wood. The destruction of medullary ray cells and the fine perforations made in the cell-walls no doubt facilitate the passage of air and of water into the wood. Where end-penetration was prevented by coating the ends of the samples with wax it was found that the difference in the amounts absorbed by the stained and by the clean wood was greater than where end-penetration also occurred.

It is therefore suggested that the main factor rendering blue-stained wood more readily attacked by certain rotting fungi is its greater porosity, which permits more rapid diffusion of the moisture and gases, as well as of the enzymes produced by the fungi.

It is well known that *Merulius lacrymans* is very sensitive to shortage of oxygen, and it is, therefore, probable that increased porosity of the wood would accelerate its growth by permitting more rapid diffusion away of the carbon dioxide of respiration. It will be noted that greater differences were

obtained in the tests with *Merulius lacrymans* than with other fungi. It is possible that there is also some chemical stimulation of the growth of the wood-rotting fungus by the products of the growth of the staining fungi, but no definite evidence for this has yet been obtained.

EFFECT OF SAP-STAIN ON RATE OF SEASONING.

Since stained sapwood appears to be able to absorb liquid water more readily than clean, it was suggested that it might also be able to dry out more quickly than sound wood, and a practical test was therefore carried out to determine if any appreciable difference in the rate of drying of stained and of clean planks could be detected. Twenty-four planks 2 inches thick showing extensive blue staining and twenty-four planks as similar as possible but which

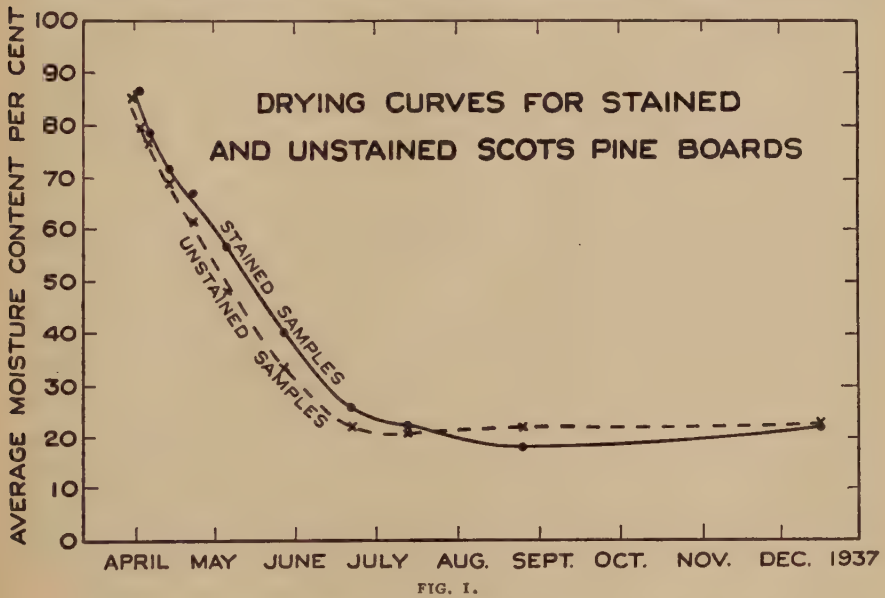

FIG. 1.

had been dipped in an antiseptic and which were entirely free from stain were selected from a pile of timber recently removed from a chamber in which conditions had been kept ideal for the development of mould and stain. These were stacked at the end of March in two similar piles alongside each other in a shed. The planks were weighed at intervals, and the rate of drying was followed up till the end of the year. The graph Fig. 1 shows the rate of drying of the groups of planks, from which it may be deduced that there was no significant difference in the rate of drying of the stained and of the clean planks. The results of this test also refute the suggestion that dipping timber in one of the new chlorinated phenol preservatives may retard its drying.

PRACTICAL SIGNIFICANCE OF RESULTS.

It has been shown that there is some justification for the popular idea that blue-stained wood is more liable to dry rot than clean wood, but that the

difference in resistance to decay is only slight. In practice this difference would be of little or no importance. Slight differences in natural resistance of timber in general are of no practical importance. Either a timber is sufficiently resistant to be used in situations where it will be exposed to the risk of fungal decay or if it is not resistant it must be protected in service.

The sapwood of practically all timbers is readily attacked under damp conditions by wood-destroying fungi, which means that timbers consisting wholly or in part of sapwood must be kept absolutely dry in service, otherwise there is a risk that they will begin to decay. If decay starts up in a joist it is of no practical moment whether 10 per cent. or 12 per cent. of weight be lost in two or three months.

From the point of view of natural durability, therefore, the presence of blue stain in the sapwood is of no importance and need not be regarded as a defect. When sapwood is present it must either be protected against the access of dampness, or if there is a risk of moisture reaching it, it must be treated with a wood preservative; for instance, ground-floor joists which may touch brickwork still damp after building should have the ends thoroughly treated with a wood preservative.

It should be noted that the tests described in this report and the conclusions based on them refer to blue stain caused by *Ophiostoma* (*Ceratostomella*) *coerulea* and similar species and do not apply to the growth of green moulds such as *Penicillium* and *Trichoderma* spp. An active growth of green moulds always tends to check development of wood-destroying fungi. Falck (2) has indeed suggested that the vigorous growth of green moulds, which he states develops on floated timber, may act as a useful deterrent to subsequent attacks by dry rot fungi. In practice green moulds often occur along with blue-staining fungi on the sapwood of planks stored under damp conditions, so that their net effect on the resistance to decay may be slight. But timber merchants and builders always tend to regard with suspicion stained and mouldy wood for several reasons: firstly, because the presence of much stain and mould indicates a high proportion of sapwood and secondly, because stain and mould are encouraged by the same damp conditions which favour the development of wood-destroying fungi. Sap-stain may be accompanied by incipient decay ('dote'), and in fact may tend to render the detection of the latter more difficult.

The general conclusion to be drawn from the results reported in this paper and in the early paper by Findlay and Pettifor is that blue stain need not be regarded as a serious defect except when the timber is required for special purposes where high toughness and a perfectly clean appearance are essential.

SUMMARY.

1. A description is given of a series of laboratory tests made to discover whether blue-stained pine sapwood is more liable than sound clean sapwood to attack by the fungi which cause dry rot in building timbers.

2. It was found that in most cases the stained sample blocks lost slightly more weight from decay than the clean blocks during the period of test.

3. Comparative tests showed that blue-stained wood absorbs water more rapidly than clean wood, and it is suggested that this greater porosity may be the reason why stained wood is decayed somewhat more rapidly than clean wood.

4. The rate of seasoning of blue-stained and of clean pine planks was compared and found to be practically identical.

5. The practical significance of these results is discussed, and it is pointed out that since all sapwood has a low natural resistance to wood-destroying fungi, slight variations in this resistance are not of practical importance and that from the point of view of resistance to rot the presence of blue stain need not be regarded as a defect.

ACKNOWLEDGEMENTS.

Thanks are due to Mr. W. A. Robertson, Director of Forest Products Research, for permission to publish this paper, and to Miss C. B. Pettifor for assistance with the statistical work.

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STRESSES AND STRAINS IN GROWING TIMBER

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INTRODUCTION.

IT is obvious that enormous stresses must be developed in large trees swaying in a gale, in trees permanently inclined to the vertical, and in the long, spreading limbs of old park trees. The nature and influence of these stresses have been studied from several distinct viewpoints, and a number of important contributions to the literature have recently appeared. The present review brings together the main conclusions of the several investigators, and indicates their practical significance. Interested readers will find fuller references to a fairly extensive literature in the papers cited.

It has long been known that leaning trees and branches develop special tissues in regions which are apparently under longitudinal compression or tension, and it has been freely assumed that the 'compression wood' of softwoods and the 'tension wood' of hardwoods are stimulated by, and developed to counteract, such stresses. The evidence for such an assumption is unsatisfactory, and Hartmann (2) and Jaccard (3,4) have sought to elucidate the responsible factors by inducing stems to produce these tissues under controlled conditions. Observing that the tissues may be stimulated by more than one factor, and that tensile or compressive stresses are not necessarily involved, these authors have suggested the general term 'reaction wood' to include both the so-called compression and tension wood. Münch (8), approaching the subject from the opposite direction, has endeavoured to show how reaction wood is adapted to withstand the stresses to which it is subjected. Others—e.g. Pillow and Luxford (10) and the present writer (1)—have compared the physical and mechanical properties of reaction wood with those of normal wood, and found differences sufficiently great to have a practical bearing on the utilization of timber.

Other workers have concerned themselves with the forces latent in normal, upright trees. These forces are liberated when the trees are felled and converted, and are apparently responsible for the heartshakes which not infrequently occur in freshly felled timber. Martley (7) and Koehler (6) have speculated as to the origin of the strains which they detected, and more recently Jacobs (5) has made a detailed study of the strains occurring in certain Australian species and has offered interesting suggestions as to their cause.

In describing the conclusions of these investigators it will be convenient to deal with reaction wood first.

REACTION WOOD.

Occurrence and Characteristics.

There is reason to believe that all woody species are capable of producing reaction wood, and in those receiving special study a deviation of only a few degrees from the vertical has been found sufficient to stimulate formation of the tissue. It may be mentioned that compression wood is usually distinguishable by the naked eye on clean surfaces of softwood timber, where it has the appearance of comparatively wide bands of relatively dark-hued summerwood. The tension wood of hardwoods is often distinguishable on the end-grain of timber sawn in the green condition, where it appears as rather lustrous, silvery zones. As a general rule, stems and branches in which reaction wood is developed are asymmetric, being hypotrophic in softwoods, with compression wood on the lower side of the pith, and epitrophic in hardwoods, with tension wood on the upper side of the pith. This rule is not invariable, and the present writer has found many hardwood branches with the widest radius on the lower side; in all instances, however, the tension wood was confined to the upper side. Compression wood tracheids differ from normal tracheids in being shorter, and in having thicker walls, a rounder cross-section permitting larger intercellular spaces, and a very oblique arrangement of the cellulose fibrils as indicated by fine spiral checks in the cell-walls. Tension-wood fibres differ from those of normal wood chiefly in the possession of a distinct, inner, gelatinous layer (sometimes referred to as a 'tertiary wall'). Some species (e.g. ash (1)) rarely form gelatinous layers, and the tension-wood fibres are similar in general appearance to those of normal wood; by means of histological stains, however, it may be shown that the secondary walls of these fibres are more or less unlignified. In spite of these characteristic differences between the reaction woods of softwood and hardwood species, the two groups of species have one significant feature in common, namely that the elements of the lower sides of the non-vertical members (i.e. of the regions normally subject to longitudinal compression) are more strongly lignified than those of the upper sides.

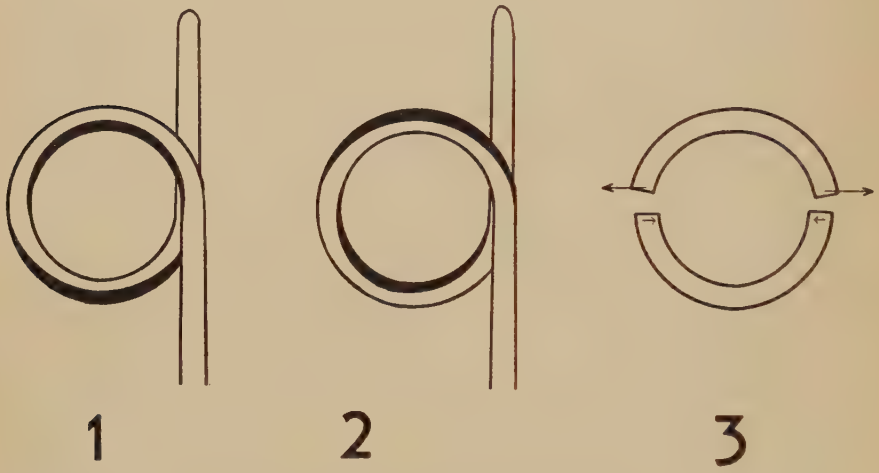
Jaccard notes that reaction wood is not always accompanied by visible histological changes and would distinguish between true tension and compression wood and the asymmetric growth due merely to irregularities in food-supply to the cambium. The latter type of growth apparently differs from the normal only in irregularities of the grain; as a rule, increased growth on one side of the tree is compensated by a smaller growth on the other, so that the total cross-sectional area is not greatly different from that of a similar, normal concentric stem.

Formation.

Münch reminds us that earlier workers appear to have regarded reaction wood as formed directly in connexion with longitudinal stresses, or as more or less pathological tissue whose especial weakness is countered by a local increase in growth rate. No particular significance was attached to the fine details

of the cell-wall; Haberlandt considered the thickness of the cell-walls as of primary importance from a mechanical viewpoint, and believed the finer details of wall structure to be merely incidental to the particular mode of thickening. Differences of opinion still exist as to whether reaction wood is more properly regarded as an abnormal tissue developed *as the result* of stresses acting on the cambium, or whether it is an active tissue developed *for the purpose* of restoring stems or branches to an erect position. Although in agreement in many essentials, Jaccard and Münch appear to differ in their support of these respective views.

Among the forces suggested by Jaccard as factors in the formation of reaction wood are gravity (which affects the stem or branch directly through



the mechanical force of weight, and also indirectly by negative geotropism), wind, the requirements of water circulation, the influence of growth substances, and those tropisms exerting an asymmetric influence, e.g. photo-, thermo-, hydro- or galvano-tropism. Under experimental conditions reaction wood has been induced by the action of centrifugal force. Under ordinary growth conditions many factors operate simultaneously, and it is impossible to say at once which is of the greatest importance, or whether tensile and compressive stresses should be added to the list. A number of carefully planned experiments by Hartmann (2) and Jaccard (3) clearly indicate that reaction wood may be formed without the stimulation of these latter stresses, and it is regarded as extremely doubtful whether they are involved under natural conditions. Many of the experiments of Hartmann and Jaccard consisted in bending shoots or branches into loops and retaining them in such positions throughout a growing season (Figs. 1 and 2). In all cases the softwood species formed 'compression wood' on the lower side of the non-vertical parts of the loops (Fig. 1) irrespective of whether these parts were in tension or compression; the hardwood species invariably formed 'tension wood' on the upper sides of

the non-vertical parts (Fig. 2), again irrespective of whether these parts were in tension or compression. Many variations in form and position of loops and bends are described, but the conclusions are essentially those reported in the preceding sentence. The experiments emphasize the characteristic tendencies of softwoods and hardwoods to form their reaction woods on the lower and upper sides of the stem respectively. Jaccard remarks that these experiments preclude, not only the influence of longitudinal stresses, but also of stimulation through the weight of the organ. The distribution of the reaction tissues strongly suggests the influence of gravity, but leaves the mode of action obscure. Jaccard suggests that the stimulation may be exerted through influence on the food-supply, and gives examples of differences in the amount of parenchyma on the upper and lower sides of branches; it is not clear, however, whether these differences have a direct connexion with the differences in the mechanical tissues.

In a recent series of experiments Jaccard (4) used a horizontal turntable of 1·7 m. diameter revolving 20 times per minute; a point at the circumference of the table was subject to a centrifugal force equal to 40 per cent. of *g*. Young spruce trees placed near the cirumference developed compression wood on the side away from the centre of the table (i.e. in such a position as to oppose the centrifugal force), and in three of the four trees used the younger growth at the tip began to turn towards the centre of the table. The behaviour of the spruce stems under centrifugal force was comparable to that of a horizontal branch under its own weight, or under gravity. Young trees of *Alnus* employed at the same time gave inconclusive results, and the experiments are being repeated.

A demonstration of the influence of weight was furnished by loading a horizontal twig of Douglas fir with a 100 gm. weight (3). The twig developed much compression wood on the lower side and during a single growing season developed a resistance to bending about 5 times that of a similar control twig.

The influence of light is strikingly illustrated by photographs of a lime tree whose branches had been trained into the shape of a fan (3). After 3 years' free growth in the open the branches had moved into an apparently normal arrangement, presumably to obtain optimum illumination. Jaccard also illustrates cross-sections of twigs in which the 'tension wood' is not confined to the upper side, but has varied in distribution from year to year, and is sometimes more or less lateral, and occasionally on the lower side. This form of distribution is attributed in part at least to the influence of light, for it is well known that shoots tend to arrange themselves so as to receive optimum illumination.

After these observations the question naturally arises whether longitudinal compressive or tensile stresses are in any way responsible for the stimulation of reaction wood. Up to the present very little attention seems to have been given to the influence of these pure stresses, and there is no direct evidence to show that they are capable of such stimulation. Pennington (9) subjected 1-year-old plants of a number of dicotyledonous species to compressive and

tensile stresses, but failed to obtain any direct correlation between the applied stresses and the development of the stem tissues. Even less is known of the influence of the other forces mentioned by Jaccard.

The consensus of present opinion is that reaction wood is stimulated mainly by the force of gravity, which is apparently able to exert influence through the medium of weight, and through such channels as negative geotropism. Although suggestions have been made of a polar effect on the distribution of food-supplies, and of growth substances, the mode of action remains obscure.

Function.

Münch's work (8) indicates the remarkable way in which reaction wood is adapted to assist in the erection of leaning stems and branches. When a softwood member containing compression wood is sawn transversely, the saw binds as soon as the blade has entered to a depth of a few centimetres from either the upper or lower side. A state of longitudinal compression on both sides of the stem is thus indicated. This is confirmed when such a member is sawn through-and-through into boards; the boards from the upper and lower sides increase slightly in length, whereas the inner boards decrease slightly. In hardwoods the reverse is found, the upper and lower sides of the member being in a state of tension and the middle in a state of compression. Jaccard, Pillow and Luxford, and Jacobs agree that compression wood is in a state of compression in the tree, and Jacobs found tension wood to exhibit a fibre tension several times greater than that of normal wood. In the light of these observations Münch suggests that the terms 'tension' and 'compression' wood take on a new meaning, and may describe active dynamic stresses rather than mere passive tissues formed under such stresses. The resultant of the stresses explains the observed tendency for members with reaction wood to move towards a normal position with respect to gravity, or an erect position, by pushing in the case of softwoods, and pulling in the case of hardwoods. Jaccard examined his loops for the existence of latent stresses, and the observations recorded support Münch's contention that the 'compression' wood is in a state of compression, and the 'tension' wood in a state of tension. The loops were cut transversely, and it was observed that in both softwoods and hardwoods the upper halves opened slightly (Fig. 3). The changes in the lower halves were less strongly marked, but in some cases there was a slight closing. The occurrence of tension wood on different sides of twigs as reported by Jaccard, and as observed in a number of hedgerow stems examined in this Laboratory, would appear to support Münch's theory that reaction wood plays an active part in determining the position of stems and branches.

Münch is not content, however, to observe the existence of these stresses; he describes characteristics of the fine structure of the cell-wall that would appear well suited to resist longitudinal stresses. It is well known that fibrils in the secondary walls of tracheids usually follow a more or less spiral course. Münch remarks that wherever a spiral arrangement is found in nature, it is always in connexion with the mechanical function, and he gives a number of

examples. At first sight, however, the slender fibrils of the wood cell-wall would appear to be singularly inappropriate to resisting longitudinal compressive stresses. It might be anticipated that under such stresses they would bend laterally, and that tubular aggregates, such as occur in a cell-wall, would simply buckle. The tendency to buckle is to some extent offset by the spiral arrangement of the fibrils, and it might be supposed that longitudinal pressure on the cells would result in a tendency to compress the spiral and unwind it, thereby pressing it more tightly against the primary wall. Now the fibrils of the outer layers pursue an extremely flat spiral, so that an internal pressure against these layers is received as a tensile stress in the fibrils. Cellulose threads are remarkable for their extremely high tensile strength, and the advantages of the fine structure are thus apparent in that a longitudinal compressive stress is transformed into a tensile stress which the wood cell is better able to resist. The spiral structure is considered also to confer advantages in resisting tensile stresses, since a radial inwardly directed pressure exerted by the outer spiral will have the effect of pressing the fibrils of the secondary wall closer together and increasing their cohesive power.

Münch further suggests that during the formation of tension wood the fibrils of the secondary wall undergo an irreversible swelling, as a result of which they exert a radial pressure on the outer layers of the wall, tending to compress the spiral windings and to shorten the cell, much as in the case of a moistened rope; it is estimated that by such means tensile stresses of 100 or even over 1,000 atmospheres may be developed. He concludes that the purpose of the spiral structure is to transform longitudinal into transverse stresses, and vice versa.

While allowing due weight to these interesting suggestions, it should be remembered that the lower sides of branches and leaning stems of both softwoods and hardwoods are usually more strongly lignified than the upper sides, according to the evidence of histological stains. Lignification, as judged by the same stains, apparently confers an increased resistance to longitudinal compression. It must be left for future work to decide whether the degree of lignification, or the spiral arrangement of the fine structure, is the more important in this connexion. It must also at present remain rather a matter of philosophy whether reaction wood is merely a passive result of cambial stimulation, or whether it is a tissue produced to perform an active function. It may be assumed, however, that the forces acting on the growing tree only influence the cambium and the cells developing from it, and it is apparent that not only do these forces stimulate the production of a tissue which differs from the normal, but the tissue carries with it into maturity latent stresses which are effective in countering the action of gravity.

Reference should also be made to experiments of Hartmann in which, by bending lateral members so as to alter their positions relative to the main axis, the production of reaction wood was induced on the upper sides of softwood branches. Although the factors involved are imperfectly understood, the observation is in general agreement with the suggestion that the function of

reaction wood is to maintain a member in a normal position in relation to gravity and to other members, and to assist disturbed members to recover such a position.

Properties.

Many comparisons of the properties of reaction wood with those of normal wood are unsupported by data, and some are merely expressions of opinion which the authors think reasonable. The most complete account of compression wood is that of Pillow and Luxford (10); these authors give data supporting the conclusions that in the five species they studied, compression wood was 15 to 40 per cent. denser than normal wood, and had a higher lignin, though slightly lower cellulose, content. The longitudinal shrinkage from green to oven-dry varied between 0·3 and 2·5 per cent. as against from 0·1 to 0·2 per cent. in normal wood; the transverse shrinkage of the compression wood was less than that of normal wood. In the green condition compression wood shows, on the average, higher values than normal wood in modulus of rupture, work to maximum load, toughness, and maximum crushing strength parallel to the grain. It is, however, also heavier than normal wood, and 'When adjustments are made for differences in weight, compression wood is lower in practically all strength properties as compared with normal wood. . . . The increase in strength properties accompanying drying is not so great for compression wood as for normal wood. Compression wood is under compression in the log and when the stresses are released, such as by sawing, extension of the compression wood portion occurs. Compression wood when manufactured into lumber is accountable for much bowing and twisting and is unsatisfactory for uses where strength and neat workmanship are essential requirements.'

The present writer has studied the properties of tension wood in several English hardwoods (1), and found that this tissue resembles compression wood in its unusually high longitudinal shrinkage during drying. Compared with normal wood of equal density, tension wood was found to be exceptionally weak in resistance to longitudinal compression, though beech tension wood was on the average slightly tougher and had a higher tensile strength. When machined in the green condition tension wood was apt to leave a rough, woolly finish. Unlike compression wood, however, tension wood appears to compare favourably with normal wood in the increase in strength on drying from the green condition.

NORMAL WOOD.

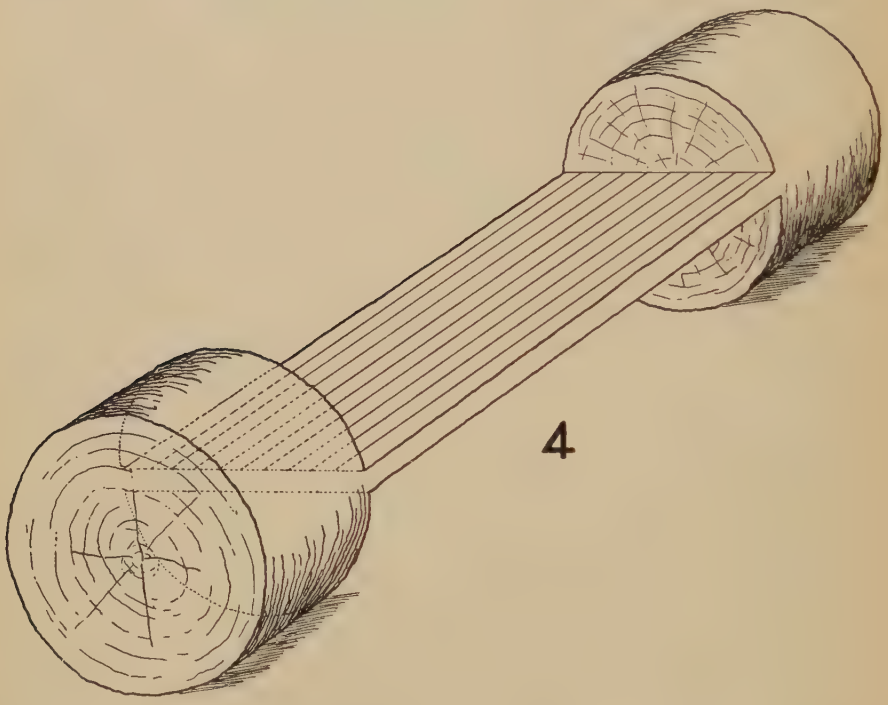
Martley's attention was attracted to the existence of stresses latent in the normal tree by observing a plank sawn in this Laboratory (7). 'The sawn ends of a perfectly flat 3-inch plank which had been sawn through the centre of a 10-foot elm log were observed to be curved and not straight. This curvature suggested that the central portion of the log might have expanded longitudinally on sawing from the tree due to the release of internal stresses in the trunk.' Seeking to explain a stress gradient reaching a maximum at the centre of the

tree and decreasing outwards, Martley attempted to calculate roughly the pressure on the base of the tree that would be built up during growth, and would be distributed unequally from the centre outwards. He estimated, however, that in an oak 150 years old the pressure at the centre would not be more than about 120 lb. per square inch, and concluded that such a small pressure could hardly be responsible for measurable changes in the length of the plank; nor could it explain the incipient compression failures which accompany brashness in some specimens of timber.

Koehler (6) attributes the shakes and cracks which are not infrequently found in freshly felled, green timber to stresses operating at right angles to the grain (i.e. transversely). 'It has been observed in a number of species that when a radial cut is made into a green disc from the bark to the pith it will close up tightly near the periphery. . . . In fact it frequently is difficult to make such a cut on account of the pinching of the saw.' This strong tendency to peripheral expansion 'indicates that the outer part of a green tree trunk is in compression tangentially'. The typical form of heart-shakes, which, in some logs of Californian redwood, may reach a width of 6 inches or more, is taken as an indication that the tangential compression is associated with a radial tension. In the absence of direct evidence as to the cause of the observed compression, the paper concludes with several interesting speculations as to how such stresses may arise. If Münch's suggestion (p. 73) is indeed correct, namely, that at the time of their formation tension wood fibrils undergo an irreversible swelling, it may well be that such swelling is a normal occurrence in all fibres and is responsible for the compression described by Koehler.

Jacobs (5) has recently given a detailed account of a longitudinal, strain-energy gradient similar to that visualized by Martley. Whereas Martley at first supposed the gradient to arise from a progressively increasing compression due to the weight of the tree, Jacobs supposes each consecutive sheath of wood to be laid down in a state of longitudinal tension; this latter process would naturally give rise to a cumulative longitudinal compression on the central cylinder. It may be supposed that such a condition, which may in one sense be likened to that of a turgid cell in which the osmotic pressure of the sap opposes the tension of the wall, plays some part in maintaining the rigidity of the tree. Jaccard has also referred to the existence of tensile stresses in newly formed wood, mentioning that these may be demonstrated by removing a young cylinder of pith from a stem of *Helianthus* or by splitting a young twig of lime or alder. In order to account for this tension Jacobs suggests that as the wood elements develop from the cambial initials 'they tend to shrink slightly, the tendency being resisted by their adhesion to the inner core. The result of this tendency to shrink would be a tension, slight enough in each fibre, but accumulating to a tremendous force along every radius as the tree increases in thickness.' It is interesting to compare this suggestion with that of Münch (see p. 73), namely, that an irreversible swelling of the fibrils at the time of formation may lead to a shortening of the cell. Tension wood may thus represent an extreme condition of a normal phase of cell-wall development.

Jacobs's studies of fibre tension were carried out on specially prepared test specimens, consisting essentially of radial planks hewn from the tree while retaining a complete round at each end to prevent splitting (Fig. 4). As each test specimen was completed, straight lines were ruled on the plank, and, after making any necessary measurements, the ends were sawn off. The internal stresses due to fibre tension were immediately released and, after allowing a few minutes for the stresses to adjust themselves, distortions were measured with reference to the ruled lines. 'In all tests made . . . the plank split down the



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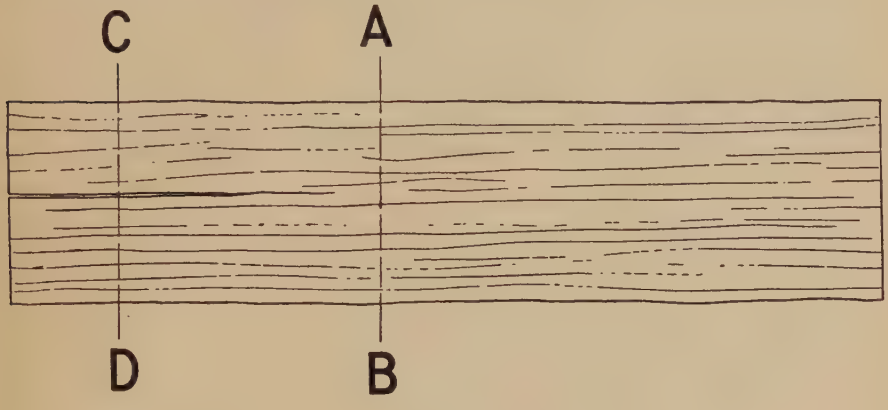
centre with a sharp report as it was cut from the ends. In some cases the split from one end extended the whole length of the plank . . .; in others it extended 3 feet or so from each end only.' The plank was cut into strips and the further distortion of the ruled guide lines measured.

Jacobs's deduction that the longitudinal stresses are distributed among individual fibres is of great interest and is helpful in explaining the behaviour of converted timber. Thus when a strip is cut from a plank it assumes the shape natural to it on the release of the latent stresses; it may subsequently be cross-cut into smaller pieces without further change of shape on the part of the pieces. On the other hand, since the tension varies from bark to pith, the distortion of a plank gradually changes as longitudinal strips are cut from it, and the longitudinal strips also change shape as they are cut from the plank. An interesting example, well illustrated in Jacobs's paper, may be represented

diagrammatically as in Fig. 5. When a split develops in a plank its length depends on the resultant of the tensile stress near the outer edges and a compressive stress near the centre, opposing the resistance of the fibres to separation. If the plank be cross-cut at *AB* the effective tensile and compressive stresses are diminished, and the split closes a little. A fresh split, however, frequently appears in the other portion of the plank, if this is long enough for the stresses to be effective. If the plank be cross-cut at *CD*, on the other hand, the split



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will open a little further, presumably owing to removal of the portion of the wood in which the stresses have been most released.

Fibre tension offers a ready explanation of heart-shakes which develop when the tree is felled. These usually consist of two shakes 'more or less at right angles to each other', and which frequently bear a direct relation to the leaning and falling of the tree. It would also appear that the magnitude of fibre tension is of an order sufficiently large to be responsible for the minute compression failures in some specimens of brash wood, particularly the 'brittle heart' which is not infrequently found at the centre of large trees of many tropical species. Although the work is still in an early stage, Jacobs gives some evidence that fibre tension is not released by drying but persists in seasoned timber.

CONCLUSIONS.

It is clear from the observations of a number of investigators that strain-energy is a normal character of growing trees. The existence of latent forces is manifested by the presence of shakes in felled timber and in the splitting and distortion that occurs when timber is converted. That the nature and extent of the strain-energy is to some extent dependent on growth conditions is shown by studies of the occurrence and properties of reaction wood. It would appear that these tissues should be regarded not so much as abnor-

malities but rather as the extreme conditions of normal trends of plant growth. Reaction wood is objectionable from the point of view of utilization because it is characterized by greater strain-energy than normal wood, and it is therefore liable to undergo more severe distortion when converted; moreover, it usually undergoes exceptionally great longitudinal shrinkage during drying, and its machining properties differ from those of normal wood.

It is highly improbable that trees can be grown without strain-energy of any kind, or entirely free in all parts from reaction wood, but the information already available would appear to indicate the possibility of some measure of control. If, from the viewpoint of the practical forester, the combined results of these workers simply emphasize the already well-known necessity for producing straight, vertical, evenly grown trees, they do so by bringing clearly to the light some serious, though as yet little appreciated, defects occasioned by growing other kinds of timber.

SUMMARY.

The conclusions of various investigators on the occurrence of stresses and strains in growing timber are reviewed.

Jaccard, Hartmann, and others have concluded that reaction wood (including 'compression' and 'tension' wood) may be stimulated by various factors but that under natural conditions of growth gravity is probably the most important. Gravity acts through the weight of the affected member, and also, in a rather obscure fashion, through movements such as negative geotropism; gravity also influences the distribution of the food-supply.

Münch has indicated how the spiral fine-structure of the cell-wall is capable of modifications that render it peculiarly suited to withstanding the stresses developed in reaction wood.

Pillow and Luxford have summarized information on the properties of compression wood and its influence on the utilization of timber; the present writer has in another publication described the properties of tension wood.

Martley has reported the occurrence of a longitudinal strain, and Koehler of a tangential strain in normal timber; Jacobs has made a detailed study of longitudinal fibre-tension, and indicated its extent and significance.

The combined results of these workers emphasize the importance of producing straight, upright, evenly grown trees.

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SOCIETY'S NEWS

NOMINATIONS OF OFFICE-BEARERS AND COUNCILLORS

MEMBERS are reminded that nominations for election of office-bearers and Councillors at the Annual General Meeting in 1940 must be in the Secretary's hands by 31 October next. There is no special form of nomination, the only requirements being that the nomination must be in writing and be signed by TWO Professional Members (i.e. Fellows or Associates). As the only function of the nomination is to have the nominee's name placed on the list of candidates, there is no advantage in having the nomination signed by more than two Professional Members nor in having more than one nomination (for the same office) in favour of any Candidate.

Nominations are required for the following:

Office-bearers, to hold office for one year: President,[1] Vice-President,[1] Editor of Journal,[1] Business Editor,[1] Secretary and Treasurer, and Auditor.

Councillors, to hold office for two years: THREE (Professional Members).

A list of those now in office will be found at the beginning of this number. The retiring office-bearers and Councillors are all eligible for re-election.

EXCURSION AND ANNUAL GENERAL MEETING

ARRANGEMENTS are being made to hold a two-day excursion to Allerston Forest on 11th and 12th July. The head-quarters will probably be in Scarborough and the Annual General Meeting held there on one of these evenings.

[1] Each must be a Fellow resident in Great Britain.

ERRATA

Attention is drawn to the undernoted mistake in *Forestry*, x (1), 1936, p. 2. In line 42, 78° F. should read 78° C., and in line 43, 65° F. should read 65° C.

NEW INTERNATIONAL ADDRESS BOOK OF WORKERS IN PLANT TAXONOMY, GEOGRAPHY, AND ECOLOGY

This book now in preparation will include particulars about workers in forestry as well as other branches. Questionnaire cards to complete information can be obtained from Editor, Chronica Botanica, P.O. Box 8, Leiden, Holland.

PROFESSORSHIP OF FORESTRY, UNIVERSITY OF OXFORD

The Electors to this Professorship propose shortly to proceed to an election of a Professor in the place of Professor R. S. Troup, whose period of office will expire on 31 July 1940. Particulars regarding applications, to be received not later than 30 September 1939, can be obtained from the Registrar, University of Oxford.

REVIEWS

An Outline of Forestry. By THOMAS THOMSON and M. R. K. JERRAM. Thomas Murby & Co., London, 1938. Price *7s. 6d.*

Review by D. W. YOUNG

MESSRS. Thomson and Jerram are to be congratulated on this excellent little introduction to forestry. They set before themselves in their preface a well-defined objective, and as they develop the subject the arrow speeds steadily to its mark.

There are two ways of writing an introduction to a science. One is that adopted by those who specialize in a particular branch; they content themselves with a brief outline of the development as a whole and proceed to illustrate the development of that science by a detailed study of the particular branch in which they are interested. The other method, which might be described as a compendium method, consists in a proportioned outline of the science in its various branches. Both methods have their uses; both may have their popular appeal. The former method gives the skilled writer more scope in that respect. He is in his own domain, and if he has the gift of expressing abstruse matters in a simple way, he can make it as absorbing and far more interesting than a detective novel without detracting from its value to the scientific reader. The method has its drawbacks, however, for the young student because it may give him a disproportionate view of the science. It is the needs of the young student which the writers of this introduction hold in the forefront. Their desire is to give these students a bird's-eye view of the subject, and at the same time an agenda upon which they can base their studies. To do this effectively they had to hold a nice balance between too much detail and generalities which for want of detail to illustrate them would be meaningless to the uninitiated. While satisfying these requirements, they hope to meet the needs of the growing circle of laymen who are sufficiently interested in forestry to want to know what it is all about.

In this double objective the authors set themselves no mean task. Compression and readability are not easily reconciled; they have succeeded admirably. The section on the form of the tree is quite a model of how these things should be done. Even the initiated will read the book with interest. In their selection of material and its presentment the authors give expression to a point of view. Whether they will be able to secure the interest of the bore they refer to in the preface who asks 'What does a forester do, does he cut down trees?' is perhaps doubtful. The book requires more application than such a one can afford. Perhaps some day a popular novelist will write a book *Down in the Forest.* It should be done because in a democratic country this sort of ignorance holds forestry back.

This brief notice would be incomplete without a word of praise of the careful way in which the task has been prepared for the press. It is exceptionally free from misprints. The format is attractive and the price very moderate.

The Classification of Tropical Woody Vegetation-Types. By J. BURTT DAVY. Imperial Forestry Institute Paper, No. 13, 1938. Price *2s. 6d.*

Review by H. G. CHAMPION

EVERY one working on the ecology of a given tract of country, even if over a whole continent or sub-continent, feels the need for a general classification of vegetation types applicable to all parts of the world. The difficulty is that there is hardly a single

worker possessed of detailed knowledge covering a sufficiently representative selection of countries to permit him to generalize from personal experience; and that we still have to reach agreement on matters of nomenclature to permit one worker to correlate with his own views the written records of another. The present position may be compared to the one which would arise in zoology if the mammalia were classified independently in North America, Europe, Central and South Africa, and India with a different conception in each area of the units corresponding to family, genus, and species, and a different basis of classification such as size, skeleton, habitat.

Dr. Burtt Davy, with an intimate knowledge of the vegetation of parts of Africa, has here attempted to correlate the published classifications of Chipp for Africa and the present reviewer for India and Burma, together with the less comprehensive accounts available for tropical vegetation elsewhere. Due regard is naturally given to the earlier classical writings of Schimper and Warming. The outcome is a scheme for tropical woody types proposed for general application, with a standard nomenclature for the major divisions.

Before proceeding to consider the acceptability of this scheme, one or two of its chief features must be mentioned. Firstly it deals only with climax types, both climatic and edaphic, the latter being a 'variation from the former due to conditions of the soil', and a climax being a community which 'appears to be stable in terms of historic time'.

Succession is intentionally not discussed, nor is the difficulty of recognition of primary or secondary seral and sub-climax communities. This makes the author's task much easier, but creates a difficult situation for any one wishing to classify under his scheme. Thus mangrove vegetation is taken as an edaphic climax, though almost every estuary shows a series of obviously successive stages as the delta creeps seawards, as the soil level is raised and the water becomes fresher, from the newly established fringe to vegetation approaching the local climatic climax; excavations confirm observational deductions and indicate that considerable changes have occurred within historic times. It is accepted as a climax because 'it remains so as long as the habitat remains suitable to it'. This statement would appear to endow every fairly well-marked stage of a primary succession with climax status, since each stage gives way to the next as the habitat gradually changes in the direction of becoming unsuited to all earlier types.

Actually, since the chief stages of a primary succession are usually to be found in a given region, it is very convenient, if it is not even essential, to fit them into any general scheme, disregarding the fact that on any given spot they are not stable in historic time and may change fundamentally in two or three human generations. Examples can be quoted where a single tree generation suffices for a complete change of type, and there are all successively slower processes of change leading on to those which definitely come under the author's definition of apparent stability in historic time. Dr. Burtt Davy has, however, arrived at much the same conclusion as the reviewer that for practical purposes, in the absence of clear proof of fairly rapid change, seral communities are best dealt with as edaphic climaxes.

Another difficult matter for solution is the treatment of montane vegetation within the tropics. The decision reached seems to depend on the particular montane areas best known to the investigator. In most parts of the Himalayan Range and its extensions, the resemblance of the vegetation of the upper slopes to that of temperate latitudes is so marked that it seems obvious that any natural scheme must bring the two close together. In other regions where lowland tropical rain forest extends up the hill-sides to altitudes compensating latitude, the resemblances between the upland and lowland vegetation seem more important. Dr. Burtt Davy has decided to include the montane

types including the coniferous forests and dwarf alpine woodland as tropical formations. There are many who will not willingly accept this treatment as satisfactory in a general scheme, but when limiting oneself to tropical and sub-tropical latitudes, it only amounts to a matter of terminology, i.e. it is of no great import whether our coniferous forests are called 'tropical high montane' or 'temperate montane'.

The scheme proposed recognizes firstly three formation types, woodland, grassland, and desert, which all can accept. The tropical woodland (including the montane) is subdivided into moist and dry sections. The moist woodland is further split into seven climatic and five edaphic climax formations. Among these, we in India could not accept the 'tropical montane bamboo forest' as separable from, or of equal status with, the others, and though we could quote examples of 'tropical palm swamp', we should again hesitate long before elevating it to the status of the other formations, if we could accept it as a climax at all.

Turning to the dry woodland, there are three formations, viz. dry evergreen, tropical savannah woodland, and tropical thornland, the first and last easily fitting Indian occurrences whilst the second has to include our dry deciduous forest, an inclusion which appears from the description to be a forced one. It is particularly here that the major difference between African and Indian vegetation evidently lies. Africa, like America, evidently has true grassland climates and all stages of vegetation hovering between grassland and close woodland, whereas in Indian these seem lacking; closer ecological studies of the relations between climate, soil, and vegetation are much required; also studies of the biotic factors which, as Clements has shown for North America, so easily shift the balance one way or the other (well within historic time). I would repeat that from all I have read of African savannah and grassland formations, they have no counterpart among Indian climax formations, although they appear to be closely paralleled by pronounced retrogression stages with fire and grazing from our tropical moist deciduous climaxes, climatic or edaphic (including seral). The difficulty over 'fringing forests' is a side branch of this main issue.

It would thus appear that whilst Dr. Burtt Davy's scheme should serve a useful purpose in drawing continued attention to a rather urgent need, it is unlikely to be found to remove it. It appears to the reviewer that a generally acceptable classification will only be forthcoming when a competent and experienced ecologist with wide knowledge of the tropical types of one continent can make an extensive tour of the others in the company of equally experienced local authorities on the subject—or better still, a committee should tour together. Here is a chance for research endowments looking for a worthy use for a grant.

The Appendix should be mentioned. It outlines the information to be recorded in field work on this subject, and suitably modified will be found useful as a check that no information likely to be needed has been overlooked. Although about 135 questions are listed, it is noted that these are far from exhaustive (even if exhausting), and the forest officer who answers them all as they stand, in addition to doing his day's routine work, will be hard worked indeed.

An Introduction to Botany. By J. H. Priestley and Lorna I. Scott. Longmans, Green & Co., London, 1938. Price 17*s.* 6*d.*

Review by the Editor

BOTANY is a large subject, and even professional botanists have their own special branches. Unfortunately for forestry, relatively few are specially interested in those aspects of botany that bear most directly on silviculture. Thus while much botanical

work is of first importance for our science, we rarely get a general text-book on botany written by a botanist who understands our point of view. The senior author of this book, Professor Priestley, is one of the few specially interested in trees, and members of this Society know of his work on different aspects of the growth of trees through his contributions to this journal; moreover, he is a stimulating personality. We therefore open this book in the hope that it will have special interest for us. We are not disappointed. This book is an ideal introduction for students of forestry, and all foresters whether university trained or not will find it interesting, stimulating, and informative.

The book in its 600 pages covers in an introductory manner the seed and germination, the life-cycle of herbaceous perennials and woody perennials, bud scales and leaves, the shoot growing-point, the metabolism of the plant, the structure of the stem, root systems, fungi as parasites and saprophytes, the reproductive phase in flowering plants, life-cycles of typical plants, biology of flower and fruit, and plant classification.

Certain sections are of special interest. The germination and early growth is treated on a quantitative basis. One thus gets a clear picture of the movement of stored food materials from the cotyledons to different parts of the plant, and the effect of respiration and photosynthesis. Although peas and beans are used as examples, the forester will find the treatment stimulating and suggestive in relation to his problems about this stage of tree growth.

The chapters on the woody perennial and the woody stem largely deal with our British trees and include a summary of the authors' important work on the radial growth of a tree. The implications of this work have not yet been fully considered in relation to silvicultural practice and their appearance in this introduction will aid by again bringing it to notice.

Throughout the book, more use than usual is made of tree examples, and this increases both its interest and value to foresters. Its principal merit, however, is that there is a freshness about the presentation of the subject, and the discussion is always stimulating and interesting. It is not a dull text-book merely recording facts. Its value is greatly enhanced by the excellent drawings by Miss Malins and Miss Scott. There is an adequate index.

An African Survey. By Lord Hailey. Price 21*s*.
Science in Africa. By E. B. Worthington. Price 10*s*. 6*d*. Oxford University Press, 1938.

Review by the Editor

In 1929 General Smuts in the course of the Rhodes Memorial Lectures at Oxford pointed out that, as conflicting principles are often applied in the social, educational, and legal fields in Africa, a comprehensive survey of what was taking place as a whole would prove of practical value to all who are connected with that continent or share responsibility for its development. A survey followed, financed by the Carnegie Corporation of New York and the Rhodes Trustees, and under the directorship of Lord Hailey on his retirement from the Governorship of the United Provinces of India. The survey took five years and covered all the territories, British, French, Portuguese, and Belgian, south of the Sahara. *An African Survey* gives in its 1,800 pages a comprehensive if necessarily a bird's-eye view of Africa: the African peoples, the study of their languages, systems of government and their objectives, law and justice, native administration, systems of taxation, agriculture, forestry, soil erosion, education, health, and so on.

The second volume arose out of a statement on the progress of scientific research in Africa, and covers the principal sciences and industries, including forestry.

In reviewing such books for a forestry journal, one naturally directs principal attention to the sections dealing with that subject. In both volumes there is a short account of forestry work in the different territories, and the organization of forest research, introduction of exotic trees, forest products, pests and diseases are lightly touched on. In the discussion that follows in the first volume, emphasis is rightly put on the desirability of pushing on with reconnaissance and stocktaking work, the need for closer co-ordination of the forest work in the different territories with perhaps a common supervising officer for East and West Africa respectively on the French pattern, and the creating of a cadre of African assistants. The principal considerations bearing on the major problem of further forest reservations are stated shortly.

In the opinion of the reviewer, however, the principal value of these books for those interested in forestry is not to be obtained from the sections on forestry, but in those on the other subjects, social and scientific, that are interrelated with forestry, and similarly for those interested in other subjects. Development in forestry and other directions in Africa will be greatly expedited when all concerned are better informed on all relevant matters. This is an essential preliminary to co-operation, co-ordination, and properly planned development. The survey and the books present this information, and if the final recommendation is carried out, namely the creation of an African Bureau to supply the information required by those concerned, the organization will be available to carry on the work which has been begun so well. Both books are supplied with maps and good indexes.

An Introduction to American Forestry. By Professor Shirley Walter Allen. McGraw-Hill Publishing Co., Ltd., London, 1938. Price 21*s*.

Review by W. L. Taylor

In his preface the author postulates that forestry is in need of a wider circle of acquaintances and this book, written as it is on broadly informative lines, is not only a textbook for forestry students but a book that is readable, and should be read, by those interested in forestry, whether in a professional or other capacity. Forestry in its wider implications does need closer acquaintanceship, particularly in Great Britain, where the art of forestry and its science are only just beginning to emerge from a long period of complacency and neglect.

In his opening chapters, the author deals with forests *vis-à-vis* man's interference in a very human way, showing the great part forests play in the development of a nation and deriving comfort from the fact that, through a stronger realization of the forester's art, the reckless devastations of former years are no longer a necessary concomitant of the exploitation of a nation's wealth in growing timber. Dealing with what forestry is, Professor Allen rightly dilates on the *business* of forestry, because the building up and conservation of forests *is* a business. His definition is that 'forestry is a science, an art, a business, and a public policy capable of, and occupied with, effecting continuous production and management of forests on suitable lands and the promotion of their beneficial use by mankind'. No one branch of knowledge is complete without the others because singly none is able to build or order forests and all are helpless without a national forest policy.

Five very full chapters are devoted to forest conservation, afforestation, and forest protection, and that on the defence of the forest from fire contains much which can usefully be read by British foresters. Exploitation is dealt with under measuring, harvesting, and the adaptation of forest products to everyday use, while the beneficial

influences and services derived from the forest are set forth in a way that can hardly fail to convince even the unregenerate.

The arguments out of which forest policy is growing in the United States can with little alteration be applied in Great Britain, where the need for a developed national policy is becoming more and more apparent; the succeeding chapters on the forest service and on forestry education cannot fail to be of interest to professional foresters.

The book concludes with a discussion upon the questions of private forestry and national planning which are presenting difficult and urgent problems on both sides of the Atlantic. There are in all twenty-one chapters and in addition the author's preface, six appendices, and an index, all of which are full of meat that is food for thought; and Professor Shirley Allen is to be congratulated on having succeeded in a difficult task—the writing of a new forestry text-book. A good work comes from Michigan.

Tree Growth. By DANIEL T. MACDOUGAL. The Chronica Botanica Company, Leiden, and Wm. Dawson & Sons, Ltd., London, 1938. Price 7 guilders or about 15*s*.

Review by Professor J. H. PRIESTLEY

THIS book is described as volume 1 of a new series of plant science books edited by Frans Verdoorn. It is in effect a restatement, presumably for European readers, of the experiments and observations upon radial growth in trees carried out by the author over a long series of years principally by means of the dendrograph, and already reported upon by the same author in the publications of the Carnegie Institution. Very extensive dendographic records have been made of growth in the conifers, especially the Californian trees, the Monterey pine, and the two species of Sequoia, but there are also discussions of very interesting observations upon the ash and oak and also upon sycamore, willow, maple, poplar, &c. Ring porous and diffuse porous hardwood types are discussed in different chapters, though the author holds the view that this classification has no real physiological or morphological basis. Certainly gradations between ring porous and diffuse porous types may be noted, but differences in growth, wood structure, and water movement in these two types have been emphasized rather than minimized by recent publications.

The dendrographic records are analysed and distinction made between fluctuations in girth not associated with growth, and probably related to the water content of the tree, and the permanent increase that is connected with the addition of new tissue elements. A very extensive literature is discussed, especially that connected with the structural changes involved in growth and their relation to both external and internal factors, but anatomical features of girth growth in trees are only treated superficially.

Chapters are devoted to specialized types of trees, including such a very special case as the tree cactus *Caruegiaea*; there is also a chapter upon seasonal length and diameter growth in roots upon which the author has made practically the only extensive dendrographic observations.

Lumber: Its Manufacture and Distribution. By R. C. BRYANT, F.E., M.A. Pp. xxiv+535. 9×6. New York: John Wiley & Sons, Inc.; London: Chapman & Hall, Ltd., 1938. Price 25*s*. (Second edition.)

Review by P. HARRIS

THE development of the lumber industry of the United States from early colonial days is traced briefly in the introduction to this volume. The manufacture of lumber began on the North Atlantic coast, gradually spread westward into the Lake

states and thence, with depletion of the virgin stands, to the southern pine forests, to the inland forests and the north-west. Generally the industry developed in the various regions from small mills supplying local requirements. These mills increased in size as transport facilities allowed outside markets to be reached, and, during the peak of production in the particular region, the output was chiefly from large mills. As virgin stands became depleted, the small mills again predominated, because they were better suited to operate on the small remaining stands and second growth timber. In recent years the greatest production has been from states between the Rocky Mountains and the west coast, manufactured by mills capable of dealing with the large-sized timber of that region. The manufacturing procedure is similar in the various states irrespective of species, apart from certain variation in the remanufacture of hardwoods and softwoods, and a description is given of lumber manufacture, typical of a medium or large size mill equipped to place finished products on the market.

The main subject-matter is divided into three parts: manufacturing plant, lumber manufacture, lumber markets and marketing. The first deals with the character and location of sawmill plants, log storage, equipment for handling the logs, sawmilling machinery, the different types of saws used, and methods of transporting the material within the mill. Under the heading of 'lumber manufacture' are discussed matters concerning labour in the industry, the conversion of logs into lumber, methods and equipment used in seasoning and remanufacture, the different classes and the dimensions of sawed products, waste in conversion and its disposal, fire prevention and insurance. Information is given in the third part about the activities of the United States lumber trade associations and legal matters arising therefrom, the grading and inspection of lumber, its transportation and distribution to domestic and foreign markets. A bibliography, a glossary of terms used in American lumber manufacture and distribution, and various useful data are given in the appendix.

The changes in economic conditions during the last twenty years and improvements in equipment and methods of manufacture made a new edition of this book advisable. Revision was especially needed in connexion with the section devoted to marketing. The volume of lumber production and consumption was at its lowest level in 1932, less than a quarter that of the peak year 1909. Though the volume has increased gradually in recent years, domestic and foreign markets have changed considerably and information on the subject is included. The purpose of this publication, as with the first edition, is to provide a text-book for instructors and students of lumbering in forest schools. It is likely to have a wider use, however, because although many of the problems discussed are peculiar to the United States, the book contains much information of general value relating to the manufacture and distribution of sawn timber.

As many readers will know, Professor Bryant died on the 1st February 1939. The forestry world is poorer by his passing.

Hedges, Screens, and Windbreaks. By Donald Wyman, Horticulturist, Arnold Arboretum, Harvard University, U.S.A. McGraw-Hill Publishing Company, Ltd., London, 1938. Price 15*s.* net.

Review by J. Alan B. Macdonald

UNTIL recently there had been no very extensive experiments with hedging materials in the U.S.A., although the Canadian Government had instituted a very complete series of hedge and shelterbelt experiments near Ottawa almost 50 years ago.

It is appropriate that this, the first of a new series of gardening books, should deal

with the hedge, screen, or windbreak without which few gardens can exist. Books on hedges have been few, and even in the gardening periodicals hedges have not received their fair share of attention. In America, also, and despite the large and increasing list of plants perfectly suited for hedging purposes, there is too often a monotonous lack of imagination in the hedges to be seen in any one district. The forester will be interested primarily in hedges suitable for dividing and sheltering nurseries, and secondly in windbreak construction and species. But no matter how little patience he may have for such frivolities as topiary, he will inevitably admire the really beautiful photographs which in themselves are convincing proof of the valuable part the hedge can play in securing shelter, privacy, or decorative effect.

If the book has a fault it lies in the relatively small space allotted to Part I, which in only 50 pages deals with the whole subject of general culture, planting practice, and afterplanting care. Of this, only five pages are devoted to windbreaks. Though some of the technique advocated may be elementary to the professional gardener or forester, it is all sound and well set out. Part II lists plants according to their uses for ornamental and protective hedges, for hedges in shady and other special situations, for windbreaks, screens (vines and the like), for edging, for topiary work, and according to their natures as narrow, columnar, or upright. Then they are listed again according to their suitability for particular regions in America. Part III—the greater part of the book—is a very complete alphabetical catalogue of over 250 individual species of varieties which are, in addition, listed according to size and the zone of hardiness in the U.S.A. for which each is suitable.

A book on the same lines for our own country is long overdue.

Der Ausschlagwald besonders in Europa und seine Umformung in Hochwald. By Dr. Johannes K. Papaioannou, Professor of Forestry in the University of Thessalonika, vol. ii, Part III: *Die Umformung des Ausschlagwaldes in Hochwald*, pp. ix+279, with 54 illustrations. Privately printed at the Triantaphyllou Press, Thessalonika, Greece, 1938. Price £1. 5*s*.

Review by Professor R. S. Troup

THIS book, written in German, is of a somewhat unusual character, comprising 259 pages (apart from 20 pages of bibliography and titles of illustrations) devoted to a discussion of one subject—conversion of coppice systems to high forest. As might be imagined, it treats the subject in very great detail, and must have entailed a vast amount of close study of the literature and the methods adopted in different countries.

The book begins with an historical outline of coppice working and conversion. Even in the time of the Romans, coppice was a regular system with annual coupes, and a distinction was made between coppice (*silvae minutae* or *silvae caeduae*) and high forest (*silvae materiae*), the latter supplying mast as well as constructional timber. In the Middle Ages a distinction was made between fruit-bearing trees (oak, beech, and others), which were protected, and non-fruit-bearing trees, which were regularly removed for fuel by unregulated selection fellings; pasturages thus played an important part, as did hunting. The distinction between coppice and coppice-with-standards became more and more pronounced towards the end of the Middle Ages, but a clear distinction between the three forms high forest, coppice, and coppice-with-standards was not made until much later by G. L. Hartig (end of the eighteenth century) and Cotta (early nineteenth century) in Germany and by Lorenz and Parade in France.

Before the nineteenth century, conversions to high forest were not conversions in the present-day sense. Views regarding the respective merits of coppice and high forest have also undergone a change. Before the nineteenth century some writers considered coppice to be the more productive and profitable form of woodland. This idea was held by the Romans, according to the writings of Cato and Pliny, the latter holding that the oftener oak and chestnut were cut the higher would be the yield obtained. By the beginning of the nineteenth century it came to be recognized, through the teaching of Hartig, Cotta, and others, that high forest gave a higher timber and total yield; conversion to high forest became the ideal for nearly all foresters, and has continued to be so, wherever practicable, to the present day. Organized conversion began in the German States between the beginning of the century and 1840, in France about 1825 (Lorenz of the Nancy School), in Switzerland about 1840 (Gehret), and in Lower Austria about 1880. The diminished value of firewood through the more extensive use of coal has given an impetus to conversion.

In the earlier conversions, gaps in the coppice were planted up, chiefly with conifers, and the worst areas were clear-felled and sown up, the better areas being left till later in order to avoid a drop in the yield; these were then regenerated for the most part naturally, both standards and selected coppice shoots being used as seed-bearers. More recently direct sowing has given way to planting. Since standards are usually light demanders, conversion by natural regeneration is generally to even-aged high forest; only where shadebearers are present is it practicable to convert to selection forest.

In regard to choice of species for the new high forest régime the following are among the general rules laid down:

(1) The species should be fast-growing, especially in youth, in order to surmount the coppice regrowth.

(2) Capacity to stand shade is an advantage, as this allows the new species to be introduced in advance under the standards while the coppice is kept back by the shade.

(3) The new species should be capable of furnishing good intermediate yields in order to counteract the drop in the yield from coppice during the conversion period.

(4) The first rotation of the new crop should be shorter than the ultimate rotation, and the species should therefore be utilizable under the shorter rotation.

The coppice areas of middle Europe are hardwood areas, and hence broadleaved species should form part of the future high forest crop. Conifers, however, have certain advantages, particularly on the poorer soils, and are largely used in middle Europe. The merits of the various species are discussed in some detail.

The greater part of the book is taken up with details of the technique of conversion under a number of different methods grouped under three main categories; A, with risk of suppression from coppice regrowth (clear-felling, shelterwood felling, and clear strip felling); B, without risk of suppression (*a*), with grubbing of stumps, temporary field crops, and artificial regeneration; (*b*) with a waiting period, causing enfeeblement of the stools; C, combined methods, leading to selection or even-aged forest, as the case may be. The descriptions are elucidated by a series of fifty-four photographic illustrations placed at the end of the book.

This book is a remarkable exposition of the technique of converting from coppice to high forest in all its details, and will be of special interest to any one concerned with the practical application of conversion methods.

Holzvorratsinventur und Leistungsprüfung der naturgemässen Waldwirtschaft (Stocktaking and Control of Yield in 'Back to Nature' Forestry). By Oberforstmeister KRUTZSCH and Oberforster Dr. LOETSCH. J. Neumann-Neudamm, 1938.

Review by W. H. GUILLEBAUD

THE title of this book includes that difficult adjective *naturgemäss*. Literally the meaning is 'in conformity with nature', but such a translation scarcely conveys the full meaning of the term, hence the use of the catchword employed above. 'Naturgemäss' forestry is at the present time all the rage in Germany, and denotes essentially a departure from the old rigid methods of pure, even-aged forests, worked on a fixed rotation. Such methods of management the German forest authorities have decided are not 'in conformity with nature', and the present objective is a free unstereotyped system with no fixed rotation, natural as opposed to artificial regeneration, mixed rather than pure woods of a definitely uneven-aged character. In short, a return to the character of the primeval mixed forests of the moister and warmer temperate regions, but, of course, subjected to an intensive form of management.

Obviously such a system of forestry requires as much, and rather more, control than the rigid systems built up so painstakingly by past generations of German foresters. In a mixed uneven-aged forest of the selection type—now considered in Germany as the *naturgemäss* ideal—it is by no means a simple matter so to regulate the cut that the growing stock is maintained, and yet it is vital that this should be achieved. It is this problem that the authors of the book under review have set out to solve.

The even-aged forestry systems have never experienced any great difficulty in regulating the annual cut. Given appropriate yield tables and an accurate stock map of the forest it is relatively a simple matter to determine the volume and age-class distribution on the ground, and then, by a combination of area and volume check, to fix the permissible cut. Other systems have been put forward in recent years in Germany but none has been wholly satisfactory. Now Krutzsch and Loetsch have devised a new method, described in great detail in this book and tested in actual practice on a number of stands of varying type. The method is based on a detailed stock map of the forest in which the unit is the stand, which is defined as a block of woodland which is relatively uniform as regards composition of species, age, and rate of growth. Each stand is then sampled by establishing a sufficient number of small, circular plots to give a reliable estimate of the composition and contents of the entire stand. The degree of sampling varies greatly. In stands of over 5 acres in area the maximum sampling density is four plots of $\frac{1}{10}$ acre each to every $2\frac{1}{2}$ acres of forest equivalent to 16 per cent. of the total area. This maximum density of sampling is only applied to mature or semi-mature stands of very irregular composition. The smallest size of plot employed is one of only 30 square yards, equivalent to a circle with a radius of 9·3 feet. In generai the size of plot is related to the number of stems on the ground, so that a plot is of such a size that it does not contain appreciably more than 20 or less than 6 to 10 trees (in even-aged stands). The authors give a diagram showing the graphical relationship between the number of trees per hectare and the area of the stand, and the number and size of the sample plots required to give a reasonable estimate of the stand.

The method of selecting the plots is not entirely random, a departure from the strict canons of statistical theory which the authors admit, but justify on practical grounds. Having delimited a given stand on the map and knowing the type of stand and the approximate number of trees per acre, the number of plots per unit area and their

size are determined from the above-mentioned curves and the sites entered on the map in such a way as to spread the plots as uniformly as possible over the area. In spacing out the plots transition zones between one stand and the next are carefully avoided. The approximate position of each plot is determined on the ground without exact measurement, and the surveyor selects a tree, wherever possible an *élite* stem (probable final-crop tree), as the centre for the circle. The ring at the end of the tape runs between two straps encircling the tree so that the end of the tape can move round to maintain a constant distance from the centre of the tree. The radius of the plot is the required length less half the diameter of the tree. The centre tree is marked with a broad paint band completely encircling the stem, but the remaining trees within the perimeter are not marked.

All the trees within the plot are measured for diameter (or girth) and the mean tree calculated. The height of one tree of approximately mean diameter is then measured with a hypsometer. In addition, every tree is classified as follows:

(A) in respect of the stem as either sound or diseased. Sound trees are further subdivided into (*a*) good stems free from defect, and (*b*) stems with some form of technical defect.

(B) in respect of crown, subdivided into (*a*) good, (*b*) medium, and (*c*) bad crowns.

The plot volumes are determined by applying form factors based on the measurement of trees felled in the normal thinnings and final fellings carried out in the forest.

This system of small, well-distributed plots covering every stand measurable in the forest provides, at relatively low cost, a reliable estimate of the conditions in the forest under examination. The authors have applied their methods to selected areas in Saxony, and it is remarkable how small are the errors as compared with any system of complete enumeration and measurement.

One point on which the authors rightly lay stress is the fact that the marked centre trees are more or less permanent and so can be identified in the future, and the same trees remeasured at periodic intervals. As a young stand gets older and the trees diminish in number, the plots may become too small to be representative, but in that case it is only necessary to lengthen the radii and so enlarge the circles. From time to time additional plots may have to be laid down. This relative permanency of their plots, achieved at a minimum cost in labour, paint, and supervision, is one of the outstanding merits of the new system. By remeasuring the same trees at successive stocktakings a large part of the error involved in random sample estimation is eliminated and, as the authors point out, any errors which may have been made in the selection of the plots in the first instance can be remedied by laying down additional plots at a later date.

The information yielded from the plots may best be indicated by reproducing in part a table given on page 133 of the book.

Two points in the following table call for some comment. The so-called 'potential increment' is determined as a result of a special investigation carried out by the authors in which a quantitative relation has been established (for spruce in a part of Saxony) between increment on the one hand, and the four values diameter, height, age, and crown quality, on the other. (How the age is to be determined in the future uneven-aged stands for which the book sets out to cater is not apparent to the present writer.) By inspection it would appear from the data at the foot of the table that the value of 147 cu.m. given as the potential increment represents the increment expected over the next 10-year period.

The second point refers to the Unit-Height Class. The authors criticize severely the present method of quality class determination which is based on the height of the trees

of mean basal area in a stand. They point out that, though this may work tolerably well in even-aged uniform stands, it tends to break down when applied to stands which, though they may be even-aged, have been subjected to very different thinning treatments. In place of the age-height quality class curves Krutzsch and Loetsch propose to substitute what they term unit-height classes. These are a series of curves relating height to diameter and were derived as follows: the diameter-height curves of 500 spruce stands measured in Saxony during 1937 were grouped together according to the age of the stands, 10 years separating each group. When plotted height against diameter, all

Total Area 5.5 ha.
Written off . . . . . .

Forest . . . . . Stand No. 16a.

Growing stock.					
Diameter class.	*Total. vol.*	*Volume in the stem quality.*			*Potential increment.*
		a.	*b.*	*c.*	
cm.	cu. m.	cu. m.	cu. m.	cu. m.	cu. m.
15–20	12	12	..	..	2
20–25	259	114	83	62	47
25–30	656	279	230	147	125
30–35	741	239	263	239	194
35–40	427	98	230	99	124
40–45	86	..	86	..	24
Total	2,181	742	892	547	516

Area of circle 0·01 ha.
Number of circles 14. Area measured 0·14 ha.
Description of Stand Spruce
Unit Height Class X. Age 78 years. Quality II.
No. of stems per ha. 807 (325 per acre)
Total volume per ha. 624 cu.m. Volume of Stand 2181 cu.m.
Potential increment 147 cu.m. per ha.
Increment per cent. 2·4
Per cent. of total volume allocated to the stem classes

a	*b*	*c*
34	41	25

Remarks...

the curves showed the same general ascending trend, but the curves of older plots of the same quality class lay above the younger. From these curves a set of fifteen generalized curves were obtained, the intervals between each representing 10 years. Another diagram shows the relation between unit-height class, age, and quality class.

The way this method works in practice is best illustrated by reference to a series of spacing plots laid out some 60 years ago in Saxony. The numbers of trees per unit area vary with the original spacing adopted, there being three times as many stems in the plot established by broadcast sowing as in the widest of the planting spacings adopted. The quality class shows a similar range of variation when based on age and mean height. When the unit height class method is applied the curves of all the plots are found to lie within the same pair of unit-height class curves and thus all belong to the same quality class. It is apparent then in this case that high density of stocking has not actually

depressed height growth; it has merely increased the number of small trees in the stand and so reduced the average height of the crop. Trees of the same diameter have approximately the same height in all of the plots.

The book under review contains many points of interest in addition to those already mentioned, notably the many ingenious diagrams employed to illustrate the text, though it must be observed that some of the graphs are not adequately explained for the benefit of the casual reader. This minor criticism apart the book is a valuable contribution to the important problem of estimating, at an economical cost, the rate of growth and production in a large forest area. The authors deserve much credit for having such a well-constructed and workable scheme.

Die heutige Bewaldung Deutschlands. (The Composition and Distribution of Forests in Germany at the Present Time.) By H. Hesmer. Paul Parey, Berlin, 1938. Second, revised and enlarged edition.

Review by W. H. Guillebaud

In this, the second edition of Hesmer's survey of German forests, the objects are twofold: firstly to show how each of the major forest species is distributed throughout post-War Germany, and secondly to indicate the broad changes which have taken place in the past century or so. At first sight such a work might seem to be of little more than general interest, except to the Germans themselves, but to take this view would be to overlook the light that a survey of this kind can throw upon the silvicultural requirements of many of the important European forest trees.

The method of presenting the facts is necessarily cartographical in the main; thus two maps are given for each species, of which one shows the proportion which the species occupies of the actual area under forest in each *Kreis* (county) and the companion map the proportion of the total land area within the *Kreis* which is occupied by the species. The relative proportions are indicated by an ingenious type of stippling and shading which brings out admirably the salient features of the distribution.

The species with the widest distribution is the Scots pine, which occupies 44 per cent. of the total area of the German forests. Hesmer points out that this species conspicuously avoids the oldest, palaeozoic rocks and also igneous strata generally, as well as high rainfall areas (40 inches of rain and over). An outstanding exception to this rule is the mountain form of Scots pine found in the Black Forest, which, both in habit and silvicultural requirements, shows a close affinity with Norway spruce. The most serious fungal disease of Scots pine in Germany is *Trametes pini*, but according to Hesmer this is almost confined to the forests in the north-east of the country; elsewhere this disease is unimportant and in some areas virtually unknown. This is a point of interest for British forestry, because it encourages the hope that we may escape this highly destructive disease.

Next to Scots pine comes the spruce as the second most widely distributed species in Germany, occupying 25 per cent. of the woodland area. The distribution is mostly closely correlated with the annual rainfall, regions with over 36 inches rainfall being usually characterized by the occurrence of extensive spruce forests. Temperature also plays an important part, the natural spruce regions being those of low winter temperature. In the relatively mild winter climate of the west German hill ranges the natural species is the beech. One curious fact to which Hesmer calls attention is that whereas in the natural spruce forests in East Prussia spruce has continually suffered in the past from epidemics of the Nun Moth, the artificially created spruce forests of the Schiefer-

gebirge on both sides of the Rhine are very free from pests or disease of any sort, and there is no record of any outbreak of the Nun Moth in this region.

Of the remaining indigenous conifers, Silver fir is the most important. It occurs now as a major species only in the extreme south of the country, in the Böhmerwald of Bavaria and in the Black Forest. In earlier times silver fir had a much wider distribution in Germany, but the spread of the clear-felling system has proved very disadvantageous to this species and it will be many decades before it is likely to recapture much of its lost territory.

Other coniferous species which receive brief mention are European larch, Japanese larch, Douglas fir, Weymouth pine, and Sitka spruce. It is interesting to note that serious damage from the Larch Sawfly has been reported from Japanese larch plantations in Schleswig Holstein.

Of the hardwood species, beech occupies much the greatest area, although the proportion has fallen very much during the past hundred years. Thus large parts of the central western hill ranges which were originally stocked with beech are now predominantly coniferous. The author remarks that beech is essentially a species which must be regenerated by natural means, and that plantations on open clearings are rarely attempted owing to the risk of damage from late frosts. Although the beech finds its optimum conditions on calcareous rocks such as Muschelkalk and the Jura, there are extensive beech forests on the New Red Sandstone, which often yields very acid soils. Hesmer quotes examples from the Devonian rocks of the Schiefergebirge where destruction of the natural beech forest results in the formation of typical Calluna heath.

There are no data available regarding the distribution of ash in Germany, which occurs only as a minor constituent of mixed broadleaved forests. Hesmer remarks, however, that ash often occurs in mixture with beech and can hold its own even on optimum beech sites.

A long section of the book is devoted to the distribution of oak, both in high forest and as coppice for the production of bark for tannin. The sessile oak appears unable to stand the low winter temperatures of the eastern plain and is lacking in East Prussia; but in general the relative distribution of the two oaks is that with which we are familiar from the text-books, namely pedunculate oak on the heavy wet soils of the lowlands and sessile oak on the drier warmer slopes of the foothills and on the lighter soils generally.

The remaining sections of Hesmer's work deal with the distribution of coppice with standards, coppice forests, birch and other softwoods, also the relative distribution of coniferous forest in 1927 as compared with 1883, and the relation between the areas under conifers and hardwoods, respectively, in the past and in the future of German forestry. Touching this last point Hesmer considers that the great demand for coniferous timber in the modern state renders any reduction in the coniferous area out of the question; on the other hand, the ideal in the future is a mixed type of forest, beech entering more than it has in the past in the coniferous areas, while conifers are likely to be introduced into the poorer quality classes of beech and other hardwoods.

Zur Systematik der waldbaulichen Betriebsarten. By Dr. Wilhelm Neubauer. Wien: Julius Springer. 144 pp. *RM.* 6.

Review by Thomas Thomson

In this monograph the author attempts to classify the numerous silvicultural systems in a systematic manner. He maintains that the fundamental characteristic which best distinguishes the different classes of high forest systems is the method of attack on the mature crop (*Hiebsart*). These methods of attack are distinguished by the varying nature of the shelter given to the young crop, as follows: (1) clear felling, giving no

shelter; (2) shelter felling, cutting of a portion of the crop so as to leave overhead shelter on the regeneration area; (3) border felling, giving lateral shelter from one side only; (4) alternate clear strip felling (*Kulissenhieb*), in which shelter is given from two sides; (5) gap felling, in which lateral shelter from all sides is given; (6) selection felling, the cutting of single stems from the close crop giving complete shelter.

Combinations of these kinds of fellings are conceivable, and in fact some of the most important silvicultural systems consist in the application of two or more of such methods. The Bavarian group system is a combination of gap fellings and border fellings, in which the felling area takes the form of a ring.

In his first scheme of classification of the silvicultural systems, the author includes the alternate clear strip system and the gap system under clear fellings, thereby reducing the main classes of systems to four, i.e. clear felling, shelter felling, border felling, and selection felling. He is conscious that this is inconsistent with his definition of clear felling which involves the absence of any shelter for the young crop. Later in the book he gives a revised classification, in which these two systems are given equal status with the other four.

The latter part of the monograph is devoted to a criticism of Dengler's contention that the size and form of the felling area is the most suitable basis for classifying the silvicultural systems. The author claims that the position of the felling, the nature of the stocking on the area itself and on adjoining areas, the direction of the progress of felling and, in short, the method of attack on the crop is more suitable. Whether the author is considered to have proved his case or not is a matter of opinion, but there is no doubt that his work contains an excellent exposition of the subject. One of the chief points in which he differs from others is in raising 'border felling' to the same status as clear felling, shelterwood felling, and selection felling. A large part of the book is devoted to the justification of this.

The following is the author's final scheme of classification.

A. High forest systems
  I. Fellings limited to part of the area (*Schlagbetriebe*)
    (1) Clear Felling System
    (2) Shelterwood Felling Systems
      (*a*) Uniform System
      (*b*) Irregular Shelterwood Systems
    (3) Border Felling Systems
      (*a*) Forms of border:
        Straight border
        Wedge shaped border
        Curved border
        Ring shaped border
      (*b*) Form of stocking:
        Clear filled border
        Shelterwood border
        Selection border
    (4) Alternate Clear Strip System
    (5) Gap System
  II. Felling area not limited to a definite part of forest
    Selection Systems
    (1) Unregulated Selection System
    (2) Regulated Selection System

B. Coppice Systems
   (1) Clear cutting
   (2) Coppice Selection System
C. Coppice with Standards.

Études sur le Gemmage des Pins en France. By A. Oudin. *Annales de l'École Nationale des Eaux et Forêts*, tome vii, fascicule 1. 1938.

Review by the Editor.

THIS memoir presents the results obtained in a series of experiments on different aspects of resin tapping carried out in France during the past fifteen years. *Pinus pinaster* is the principal species tapped and the most extensive area is on the Landes where there are over two million acres of this species. *P. pinaster* is also tapped in the south-east, while *P. halepensis* is occasionally tapped in Provence. Scots pine, Corsican pine, and Austrian pine have only been tapped experimentally.

The Hugues method of tapping is used in France. Various other methods have been experimented with, but the former has given the best results so far. Various minor modifications are suggested, however, such as a lid to cover the pot to reduce evaporation and exclude impurities, and changes in the size of the cut and duration of tapping, the latter two changes to reduce costs.

The production of resin depends not on the normal resin content of the tree, but on the abnormal development of resin canals in the new tissue arising after wounding. It is, therefore, pathological. In the Landes, air humidity influences production, and stands near the sea give about 10 per cent. more production than those farther inland. The production is greatest from vigorous trees with crowns in the light, and various experiments are in progress on the influence of thinning. On the evidence at present available, a density of about 200 trees per acre at 20 years, and 100 at 40 years is considered best for Maritime pine. It is likely, however, that the marked variation in resin production of individual trees may be due, at least in part, to inherited characteristics. Trees giving very high production have been selected, seed produced by self-fertilization gathered from them, and the progeny is being raised. The results of these experiments will be looked forward to with interest and may in future lead to a marked increase in production per tree as in the case of rubber. The experiments cover a considerable number of other points, such as the effect of more than one cut per tree, orientation of cut, influence of tapping on the quality of the timber which is stated to be favourable, and so on, a chapter being devoted to each species. Climatic and soil data for the different experimental sites are given, and there are 22 photographs illustrating methods of tapping and experimental methods. As most of the experiments were laid down some years ago, the lay-outs do not appear to conform to modern ideas, and this is a disadvantage, particularly as differences between treatments are often small. Nevertheless, there is much of interest and value in this memoir.

NOTICES

The North American Assault on the Canadian Forest. By A. R. M. Lower and others. Oxford University Press, 1938. Price 16*s.*

THIS book is an interesting and well-documented account of the rise and development of the lumber industry in Canada from the historical and economic points of view. Lumber followed fur as the staple product of the forest. Its first development was the result of Napoleon's attempt to cut Britain off from her Baltic supplies of timber, but its great expansion was due to the growth of the United States. The important part that lumber has played in the development of Canada, directly and indirectly, is clearly brought out. Professor Lower deals mainly with the St. Lawrence basin, while Professor Carrothers contributes a section on 'Forest Industries of British Columbia', and Dr. Saunders one on 'Forest Industries in the Maritime Provinces'. The book is well illustrated by maps and diagrams.

A Gallery of Gum Trees. By A. W. D'Ombrain. Illustrated by Miss Tydfyl Evans. H. K. Lewis & Co., Ltd., London, 1938. Price 14*s.* 6*d.*

WE owe this beautiful book to the curiosity of an Australian country doctor to know something about the principal species of *Eucalyptus* in his neighbourhood. Twenty species are described in a simple way, and each illustrated by a reproduction in colour of delightful paintings in water colour by the tree artist Miss Tydfyl Evans.

Report of the National Forest Park Committee (*Forest of Dean*). 1938. H.M. Stationery Office, London. 1938. Price 6*d.*

THE Committee recommends the establishment of a forest park in the Forest of Dean on lines similar to those in Argyll and Snowdonia.

The Imperial Forestry Institute, University of Oxford. Fourteenth Annual Report.

THE Report describes the activities of the different sections of the Institute. In the Introduction, the proposed changes in teaching forestry at Oxford are set out. These were circulated to the press and will be already known to readers.

A Forestry Tour in 1937. By L. Chalk. Imperial Forestry Institute Paper, No. 16. Price 2*s.* 6*d.*

THIS paper gives an interesting account of Dr. Chalk's world tour and the contacts he made.

Forêts Privées, Volume I. *Europe.* Institut international d'Agriculture, Rome, 1938.

THIS publication gives in French information regarding private forests in different countries in Europe, such as legislative measures in force, government intervention in management, taxation, measures taken to encourage private forestry, &c. The

information was compiled mainly from replies to a questionnaire sent out by the Institute, hence it varies in the detail given, but the publication will provide a useful additional source of information on this important subject.

The Disease caused by Trametes Pini (Thore) *Fries on White Pine* (*Pinus Strobus* L.). By W. R. Haddow. *Trans. Roy. Canadian Institute*, No. 47, vol. xxii (1). 1938.

On the Classification, Nomenclature, Hosts, and Geographical Range of Trametes Pini (Thore) *Fries*. By W. R. Haddow. *Trans. Brit. Mycological Society*, vol. xxii (1) and (2). 1938.

MR. HADDOW has been studying for a number of years this important fungus causing heart-rot of pines in different parts of the world, and he contributed an article to *Forestry*, Volume VIII, on this subject. The attention of readers is drawn to these two further papers.

The Occlusion of Pruning Wounds in Norway Spruce (*Picea excelsa*). By A. Paterson. *Annals of Botany*, New Series, vol. ii (7). 1938.

THIS paper describes with numerous illustrations the stages in occlusion of spruce, principally from the anatomical point of view.

Application of Statistical Methods to some Australian Forest Problems (volume 1). By T. M. Stoate and C. E. Lane Poole. Commonwealth Forestry Bureau, Bulletin No. 21. 1938.

THIS bulletin describes methods of statistical analysis, using Australian forestry data.

Notes on Pruning Pinus radiata. Part I. *Observations on Features which influence Pruning.* By M. R. Jacobs. Commonwealth Forestry Bureau, Bulletin No. 23.

THIS bulletin describes the features of the tree that influence pruning, the effect of espacement on tree form, and the effect of pruning on growth and quality of the crop, all in relation to *P. radiata* in South Australia. It is well illustrated.

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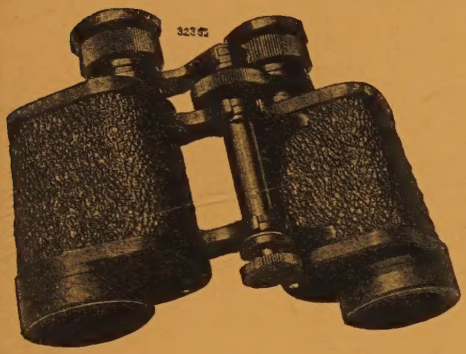

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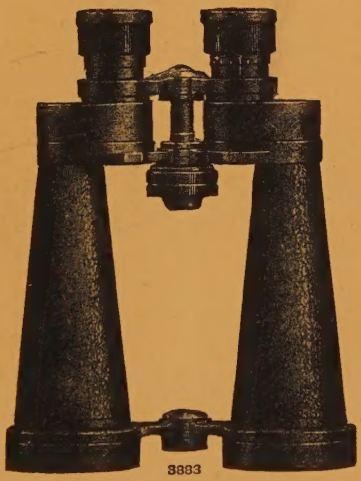

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